

Phosphorus P by HPLC (Silica) Barrier Fabrics

Std ppm	Area	Constant	Regression Output	Std ppm	Area	Constant	Regression Output
0	0	15562.2	277154	0	0	-11581.8	20675.9
15.4	2507108	Std Err of Y Est	30075.32	15.4	277154	Std Err of Y Est	20675.9
32.3	528380	R Squared	0.00065	32.3	534154	R Squared	0.99897
62.5	1125478	No. of Observations	5	62.5	1098440	No. of Observations	5
142.9	2507150	Degrees of Freedom	3	142.9	2508550	Degrees of Freedom	3
		X Coefficient(s)	18231.07			X Coefficient(s)	17818.6
		Std Err of Coef	265.4387			Std Err of Coef	18150.12

Sample	Area	Po, ppm	Vol (ml)	Wt (mg)	%Po	%P	Avg P per Sample	RSD per Sample	Minimum	Maximum
CL11	407101	22.18	50	87.6	1.187	0.387	0.621	0.159	0.336	0.843
CL1C	862310	44.86	50	127.9	1.840	0.600				
CL2R	437865	24.86	50	98	1.280	0.414				
CL3C	378042	21.56	50	104.8	1.030	0.336				
CL11L	1018194	56.72	50	122	2.326	0.756				
CL11C	936432	62.20	50	113.7	2.268	0.746				
CL18R	729378	40.86	50	110.7	1.846	0.602				
CL18C	832580	46.51	50	103.4	2.248	0.734				
CL27L	918432	51.22	50	143	1.781	0.564				
CL27C	1048078	58.32	50	163.1	1.806	0.622				
CL28R	1786075	44.67	50	112.3	1.888	0.644				
CL28C	961918	32.43	50	114.8	1.827	0.643				
CL31L	861918	47.57	50	113.8	2.000	0.682				
CL31C	1088340	80.56	50	187.1	1.827	0.628				
CL38R	1216487	67.56	50	139.6	2.002	0.643				
CL38C	1108040	81.67	50	136	2.267	0.740				
CL41L	1302277	72.26	50	146.3	2.470	0.808				
CL41C	1181071	86.16	50	129.7	2.551	0.832				
CL48R	522110	29.46	50	138.8	1.654	0.544				
5244-11	431388	24.51	100	144.8	1.985	0.653	0.478	0.086	0.286	0.637
5244-1C	351534	20.13	100	112.7	1.785	0.563				
5244-6C	351534	11.32	100	124.6	0.807	0.268				
5244-11L	325450	13.88	100	135.8	1.382	0.464				
5244-11C	284810	14.81	100	107.7	1.265	0.462				
5244-18R	387822	22.87	100	127.2	1.782	0.641				
5244-18C	334853	18.22	100	131.2	1.465	0.478				
5244-21L	474394	26.87	100	137.7	1.851	0.637				
5244-21C	263838	15.32	100	122.6	1.250	0.408				
5244-28R	466846	25.84	100	141.1	1.833	0.686				
5244-28C	287135	15.50	100	140.6	1.088	0.356				
5244-31L	378448	21.47	100	140.6	1.527	0.486				
5244-31C	275380	16.56	100	135.6	1.175	0.363				
5244-36R	386820	22.24	100	130.6	1.703	0.666				
5244-36C	286872	16.55	100	124.2	1.262	0.408				
5244-41L	266272	16.48	100	118.3	1.263	0.451				
5244-41C	284810	14.81	100	123.4	1.023	0.361				
5244-48R	287886	14.32	100	138	1.173	0.383				
5244-48C	330858	18.58	100	112.4	1.088	0.351				

4044-27	823110	35.02	100	158.2	2.214	0.722			
4044-27c	830083	35.40	100	150.3	2.259	0.709			
4044-28	480063	28.22	100	118.8	2.375	0.775			
4044-28c	560750	31.06	100	141	2.202	0.719			
4044-29	520063	29.06	100	128	2.233	0.781			
4044-29c	453477	25.72	100	100.6	2.052	0.633			
4044-30	430629	24.46	100	118.7	2.090	0.684			
4044-30c	630460	30.98	100	144.6	2.460	0.806			
4044-31	450063	26.53	100	117.6	2.468	0.707			
4044-31c	550780	31.55	100	132.2	2.468	0.778			
4044-32	450063	32.50	100	130.8	2.368	0.778			
4044-32c	560780	32.50	100	140.1	2.364	0.788			
4044-33	550780	31.25	100	136.5	2.308	0.753			
4044-33c	560780	31.25	100	147.0	2.353	0.735			
4044-34	641546	38.03	100	148.7	2.456	0.801			
4044-34c	413535	23.53	100	101.5	2.318	0.759			
4044-35	811780	34.40	100	180.3	2.146	0.700			
4044-35c	532821	30.07	100	131.8	2.265	0.746			
4044-36	510872	29.29	100	123.2	2.378	0.778			
4044-36c	413049	23.54	100	124.7	1.987	0.618			
4044-37	522829	20.51	100	133	2.278	0.724			
4044-37c	560780	33.99	100	134.6	2.403	0.817			
4044-38	460867	20.51	100	113.3	2.448	0.786			
4044-38c	460867	24.79	100	153.4	2.368	0.786			
4044-39	560780	34.79	100	131.3	2.608	0.861			
4044-39c	309082	18.00	100	71.3	2.504	0.824			
4044-40	417067	27.56	100	100.6	2.342	0.865			
4044-40c	800406	34.39	100	142.2	2.416	0.786			
4044-41	877287	38.06	100	168.6	2.283	0.746			
4044-42	723349	41.18	100	156.6	2.631	0.866			
4044-43	317282	21.60	100	94.8	2.278	0.744			
4044-43c	503832	28.83	100	118.2	2.427	0.782			
4044-44	358901	20.85	100	87.4	2.365	0.778			
4044-45	416078	23.95	100	86.4	2.434	0.794			
4044-46	450881	20.24	100	108.5	2.418	0.786			
4044-46c	450881	20.24	100	116.7	2.075	0.677			
4044-47	562829	27.60	100	133.3	2.075	0.677			
4044-47c	417067	21.80	100	88.4	2.481	0.815			
4044-48	317750	21.80	100	88.4	2.411	0.787			
4044-48c	381562	22.07	100	88.6	2.394	0.746			
4044-49	480462	28.41	100	118.2	2.403	0.784			
4044-49c	381562	22.07	100	118.2	2.087	0.675			
4044-50	440342	25.48	100	106.6	2.413	0.787			
4044-50c	440342	25.48	100	112.1	2.288	0.748			
4044-51	500875	20.09	100	124.9	2.320	0.790			
4044-51c	447842	25.79	100	109	2.386	0.772			
4044-52	402756	73.23	100	86.0	2.430	0.783			
4044-52c	800813	34.67	100	135.4	2.675	0.840			
4044-53	423255	24.67	100	111.2	2.442	0.731			
4044-53c	560780	24.79	100	120.8	2.444	0.786			
4044-54	517058	21.10	100	114.8	2.458	0.800			
4044-54c	541087	31.02	100	118.2	2.604	0.866			
4044-55	380287	22.33	100	89.4	2.668	0.815			
4044-55c	500409	28.87	100	120.1	2.413	0.787			
4044-56	433362	24.87	100	108.3	2.308	0.752			
4044-56c	560104	33.77	100	128.1	2.678	0.874			
4044-57	477515	27.45	100	111.9	2.463	0.801			
4044-57c	820737	36.48	100	124.3	2.665	0.932			
4044-58	543340	31.15	100	121.2	2.670	0.839			
4044-58c	550862	31.89	100	120.8	2.672	0.862			
4044-59	560780	34.29	100	141.8	2.416	0.786			
4044-59c	570836	32.96	100	134.1	2.400	0.803			
4044-60	461151	27.67	100	132.2	2.400	0.786			
4044-60c	461151	27.67	100	132.2	2.400	0.786			
4044-61	517058	21.10	100	114.8	2.458	0.800			
4044-61c	517058	21.10	100	114.8	2.458	0.800			
4044-62	812046	36.04	100	129	2.716	0.866			
4044-62c	540878	31.35	100	118.6	2.321	0.757			
4044-63	563201	31.70	100	138.6	2.321	0.757			
4044-63c	563201	31.70	100	151.7	2.208	0.720			
4044-64	560134	37.49	100	150.6	2.488	0.812			
4044-64c	646727	38.95	100	150.2	2.480	0.803			
4044-65	814283	35.13	100	134.4	2.614	0.853			
4044-65c	819778	38.80	100	170.7	2.273	0.742			
4044-66	550869	31.89	100	135.4	2.353	0.786			
4044-66c	537078	30.80	100	151.1	2.058	0.685			
4044-67	443509	29.57	100	106.6	2.423	0.781			
4044-67c	242562	24.29	100	132.8	1.712	0.588			
4044-68	460867	24.79	100	147.0	1.664	0.546			
4044-68c	460867	24.79	100	132.9	1.785	0.676			
4044-69	409403	23.48	100	103.1	2.283	0.746			
4044-69c	407712	23.53	100	103.1	2.204	0.719			
4044-70	410088	24.03	100	98.1	2.425	0.781			
4044-70c	398872	22.81	100	89.3	2.666	0.837			
4044-71	529716	30.38	100	128.6	2.398	0.782			

4844 demo 2f	344604	20.00	100	73.7	2.714	0.868			
4844 demo 3a	356248	20.83	100	83.4	2.698	0.815	0.763	0.062	0.812
4844 demo 3b	380442	22.00	100	87.1	2.528	0.824			
4844 demo 3c	833528	36.71	100	128.5	2.788	0.812			
4844 demo 3d	415328	23.88	100	116.4	2.660	0.672			
4844 demo 3e	842135	38.89	100	182.8	2.767	0.738			
4844 demo 3f	642027	31.07	100	127.2	2.443	0.787			

June 8, 2001 Barrier Fabrics
P Analysis by ICP

Measured		Regression Output		Std Actual		Regression Output	
Std Actual	Measured ppm	Constant	Std Err of Y Est	ppm	Measured ppm	Constant	Std Err of Y Est
0	0.2111	0.418408	0.445207	0	0.002	0.135560	0.222441
1	1.18	0.96897	0.96897	1	1.098	0.968978	0.968978
5	5.826			5	5.483		
10	11.5			10	10.07		
25	26.36			25	26.34		
		X Coefficient(s)	1.048246			X Coefficient(s)	1.063463
		Std Err of Coef	0.02198			Std Err of Coef	0.010822

Sample	Measured ppm	Actual ppm	Vol (ml)	Wt (mg)	%P	Avg P per Sample	STD per Sample	Minimum	Maximum
Water Extractions									
4844 demo 2a	26.87	26.06	100	103.1	2.429	2.306	0.072	2.218	2.428
4844 demo 2b	48.82	47.13	100	202	2.333				
4844 demo 2c	23.97	22.47	100	98.1	2.267				
4844 demo 2d	21.79	20.39	100	86.3	2.283				
4844 demo 2e	30.97	29.16	100	126.8	2.299				
4844 demo 2f	17.56	16.35	100	73.7	2.218				
4844 demo 3a	20.96	19.80	100	83.4	2.360	2.371	0.207	2.069	2.590
4844 demo 3b	20.52	19.18	100	87.1	2.202				
4844 demo 3c	28.37	26.57	100	129.5	2.098				
4844 demo 3d	31.1	28.27	100	118.4	2.515				
4844 demo 3e	44.5	42.06	100	162.6	2.696				
4844 demo 3f	33.92	31.66	100	127.2	2.513				
4844-1i	34.61	32.72	100	131.3	2.482	2.413	0.104	2.203	2.696
4844-1c	18.88	17.78	100	71.3	2.495				
4844-2i	24.78	23.40	100	100.6	2.328				
4844-2c	36.91	34.91	100	142.2	2.468				
4844-3i	41.87	39.43	100	168.6	2.538				
4844-3c	41.39	39.16	100	156.0	2.501				
4844-4i	24.41	23.04	100	94.8	2.431				
4844-4c	29.51	28.17	100	119.2	2.363				
4844-5i	21.95	20.71	100	87.4	2.369				
4844-5c	24.4	23.03	100	98.4	2.341				
4844-6i	27.23	25.72	100	108.6	2.368				
4844-6c	30.61	28.83	100	118.7	2.479				
4844-7i	32	30.25	100	133.9	2.259				
4844-7c	21.88	20.43	100	88.1	2.319				
4844-8i	23.72	22.39	100	90.6	2.471				
4844-8c	22.91	21.82	100	96.6	2.238				
4844-9i	29	26.45	100	118.2	2.236				
4844-9c	29.95	28.30	100	108.4	2.611				
4844-10i	26.53	24.86	100	106.6	2.365				
4844-10c	28.05	26.50	100	112.1	2.384				
4844-11i	32.41	30.84	100	124.9	2.453				
4844-11c	29.73	28.29	100	106	2.577				
4844-12i	28.06	23.86	100	96.6	2.475				
4844-12c	36.21	34.24	100	135.4	2.529				
4844-13i	28.21	27.80	100	111.2	2.482				
4844-13c	34.35	32.48	100	129.5	2.508				
4844-14i	31.45	29.72	100	116	2.519				
4844-14c	25.82	24.18	100	118.2	2.384				
4844-15i	23.01	21.71	100	89.4	2.429				
4844-15c	31.78	30.52	100	120.1	2.496				
4844-16i	27.82	26.26	100	108.3	2.426				
4844-16c	32.18	30.42	100	126.1	2.412				
4844-17i	28.45	26.88	100	111.9	2.402				
4844-17c	31.54	29.81	100	124.3	2.398				
4844-18i	30.58	28.90	100	121.2	2.384				
4844-18c	31.8	30.06	100	120.8	2.488				
4844-19i	33.04	31.23	100	141.8	2.203				
4844-19c	33.84	31.99	100	134.1	2.398				
4844-20i	30.72	29.03	100	122.2	2.378				
4844-20c	35.28	33.36	100	135.7	2.458				
4844-21i	31.55	29.82	100	128.8	2.315				
4844-21c	31.75	30.01	100	129	2.326				
4844-22i	34.19	32.33	100	119.9	2.698				
4844-22c	32.24	30.47	100	136.6	2.251				
4844-23i	37.65	35.61	100	151.7	2.347				
4844-23c	38.8	36.72	100	150.6	2.437				
4844-24i	40.1	37.64	100	150.2	2.528				
4844-24c	38.3	36.23	100	134.4	2.695				
4844-25i	40.87	38.67	100	170.7	2.265				
4844-25c	33.82	31.97	100	135.4	2.351				
4844-26i	38.87	36.77	100	151.1	2.433				
4844-26c	26.94	25.44	100	105.5	2.412				
4844-27i	38.98	36.76	100	158.2	2.324				
4844-27c	38.73	36.63	100	150.3	2.437				
4844-28i	30.51	28.83	100	116.8	2.427				
4844-28c	35.65	33.90	100	141	2.404				
4844-29i	30.58	28.90	100	128	2.258				
4844-29c	25.53	24.10	100	100.8	2.391				
4844-30i	28.28	26.72	100	116.7	2.289				
4844-30c	38.01	35.86	100	144.6	2.466				
4844-31i	29.91	28.26	100	117.8	2.399				
4844-31c	33.85	32.10	100	132.3	2.426				
4844-32i	34.27	32.40	100	130.8	2.477				
4844-32c	37.65	35.81	100	140.1	2.842				
4844-33i	32.77	30.86	100	136.5	2.286				
4844-33c	38.84	36.74	100	147.9	2.484				
4844-34i	38.79	36.69	100	146.7	2.521				
4844-34c	25.36	23.84	100	101.5	2.359				
4844-35i	37.76	35.71	100	160.3	2.228				
4844-35c	34.29	32.42	100	131.6	2.484				
4844-36i	32.81	30.83	100	123.2	2.522				
4844-36c	33.32	31.60	100	124.7	2.526				
4844-37i	32.73	30.94	100	133	2.328				
4844-37c	36.17	34.20	100	134.8	2.541				
4844-38i	26.58	25.10	100	113.3	2.216				
4844-38c	40.31	38.13	100	153.4	2.486				

Water Soak
P Analysis by ICP, 06/07/01

Measured		Actual		Vol (l)		Wt (g)		%P		P % in form of	
Std Actual	Measured ppm	Std Actual	Measured ppm	Vol (l)	Wt (g)	%P	PO ₄ ppm	PO ₄ %	PO ₄ P %	PO ₄ P %	PO ₄ ppm
0	0.2111	0	0.42				0				
1	1.18	1	35.14	80	223.8	1.256	898.16	1.173	0.383		30.8
5	5.826	5	76.93	80	271.6	2.088	1207.68	1.779	0.582		27.8
10	11.5	10	16.40	80	241.7	0.843	874.86	1.447	0.472		87.0
25	26.36	25									

June 14, 2001 Barrier Fabrics
P Analysis by ICP

Std Actual Measured
 ppm ppm

0 -0.1494
 1 0.9472
 5 5.543
 10 11.07
 25 25.08

Regression Output:

Constant 0.236133
 Std Err of Y Est 0.578223
 R Squared 0.997624
 No. of Observations 5
 Degrees of Freedom 3

X Coefficient(s) 1.007564
 Std Err of Coef. 0.028391

Sample	Measured ppm	Actual ppm	Vol (ml)	Wt (mg)	%P	Avg P per Sample	PO ₄ ppm	PO ₄ %	PO ₄ , P %
fabric 2 water extract	15.17	14.82	35	203.8	0.255		40.300	0.198	0.065
fabric 2a acid digest	19.99	19.61	10	17.7	1.108	1.096			
fabric 2b acid digest	14.11	13.77	10	12.7	1.084				
uk cover water extract	0.6639	0.42	10	256.3	0.002		0		
uk cover a acid digest	8.121	7.83	10	16.6	0.471	0.484			
uk cover b acid digest	7.033	6.75	10	13.6	0.496				



United States
CONSUMER PRODUCT SAFETY COMMISSION
Washington, D.C. 20207

MEMORANDUM

DATE: 12 MAR 2001

TO: Linda Fansler, Division of Engineering
Directorate for Laboratory Sciences

Through: Susan Ahmed, Ph.D., Associate Executive Director *sa*
Directorate for Epidemiology

Russell Roegner, Ph.D., Director *RR*
Division of Hazard Analysis

FROM: C. Craig Morris, Ph.D., Mathematical Statistician *CCM*
Division of Hazard Analysis

SUBJECT: UK Chair Upholstery Flammability Test Results

This document provides a statistical analysis of data from CPSC laboratory tests assessing the flammability of upholstery fabric on a diverse set of 27 chairs from the United Kingdom (UK).

cc./ Dale Ray, ECPA, Project Manager



UK Chair Upholstery Flammability Test Results

February 2001

C. Craig Morris, Ph.D.
U.S. Consumer Product Safety Commission
Directorate for Epidemiology
Division of Hazard Analysis
4330 East West Highway
Bethesda, MD 20814

Executive Summary

Upholstery flammability tests were conducted on upholstery from 27 UK chairs and on additional UK fabric of the same type as that on the 27 chairs. A total of 5 unique tests were conducted: 3 small-flame-ignition tests and 2 cigarette-ignition tests. Tests were conducted on both the full-scale chair and on bench-mounted "mockups." There were 2 tests on the full-scale chair: one small-flame-ignition test and one cigarette-ignition test. There were 2 small-flame-ignition mockup tests: one used fabric taken from the chairs, or identical to that on the chairs, in the standard mockup using standard foam, while the other used fabric taken from the chairs, or identical to that on the chairs, in the standard mockup using UK foam padding. Finally, there was one cigarette-ignition mockup test using fabric taken from the chairs and standard foam padding; however, because an insufficient number of trials of the cigarette-ignition mockup test were conducted, no statistically valid conclusions can be drawn about that test. Several replications of each test were conducted on fabric from each chair, but the number of replications varied across chairs and tests for logistical reasons. Not all tests were run on all chairs.

For comparison purposes, the proportion of passes was computed for each available combination of chair and test (e.g., chair 13 passed 2 out of 5 full-scale small-flame-ignition tests, yielding a score of 0.4 for that chair on that test). Replications of the same test on the same chair fabric tended to be consistent as evidenced by a preponderance of pass proportions near 0 or 1 in the test data: only 18 of the 116 proportions obtained across all tested combinations of 27 chairs and 5 tests differed from 0 or 1.

None of the 3 small-flame-ignition tests differed significantly from each other, but the full-scale small-flame-ignition test differed significantly from the full-scale cigarette ignition test, and the 2 cigarette-ignition tests differed significantly from each other.

The small-flame-ignition tests (full-scale = 1, standard mockup = 2, mockup with extra foam = 3) were positively intercorrelated, $\tau_{12} = .68$, $\tau_{13} = .41$, $\tau_{23} = .70$, indicating consistency of the small-flame-ignition results across the 27 chairs. In addition, the full-scale cigarette-ignition test (4) was positively correlated with the mockup cigarette-ignition test (5), $\tau_{45} = .66$. Although correlations of the cigarette-ignition full-scale and mockup tests with the 3 small-flame-ignition tests were all positive, ranging from .05 to .34, none was statistically significant; the small sample sizes and preponderance of proportions of 1.0 preclude interpretation of these nonsignificant correlations.

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UK Chair Upholstery Flammability Test Results

Purpose

CPSC staff have prepared a draft furniture upholstery flammability standard and test protocol and designed a flammability test apparatus as part of the draft test protocol. The draft standard is modeled after an existing United Kingdom (UK) standard. In exploratory trials assessing the draft test protocol, CPSC Laboratory Sciences staff conducted flammability tests on several UK chairs and additional UK fabric and foam of the same type as that on the chairs. It is unknown whether the UK chairs and fabric were all from lots which would pass the UK standard, although CPSC staff specified that the obtained units were to comply with the UK standard.

Design

Upholstery flammability tests were conducted on upholstery from 27 UK chairs and additional fabric of the same type as that on 4 of the 27 chairs. A total of 5 unique tests were conducted: 3 small-flame-ignition tests and 2 cigarette-ignition tests. Tests were conducted on both the full-scale chair and on bench-mounted "mockups." There were 2 tests on the full-scale chair: one small-flame-ignition test and one cigarette-ignition test. There were 2 small-flame-ignition mockup tests: one used fabric taken from the chairs, or identical to that on the chairs, in the standard mockup using standard foam, while the other used fabric taken from the chairs, or identical to that on the chairs, in the standard mockup using UK foam padding. Finally, there was one cigarette-ignition mockup test using fabric taken from the chairs and standard foam padding; however, because an insufficient number of trials of the cigarette-ignition mockup test were conducted, no statistically valid conclusions can be drawn about that test. Several replications of each test were conducted on fabric from each chair, but the number of replications varied across chairs and tests for logistical reasons. Not all tests were run on all 27 chairs.

Results

The proportion of replications passing the test was computed for each available combination of chair and test (e.g., chair 13 passed 2 of 5 full-scale small-flame-ignition test replications, yielding a score of 0.4 for that chair on that test). Proportions passing are given in Appendix A. Replications of the same test on the same chair fabric tended to be consistent as evidenced by a preponderance of pass proportions near 0 or 1 in the test data: only 18 of the 116 proportions obtained across all tested combinations of 27 chairs and 5 tests differed from 0 or 1. (see Appendix A). Consistency of test results was also assessed by comparisons of the mean proportion passing the tests and correlational analyses.

Mean Proportion of Passes

Table 1 gives, for each of the 5 tests, the mean proportion of passes, standard error (SE), sample size (n), and 95% confidence interval for the mean proportion. The mean proportions passing were .74 for the full-scale small-flame-ignition test, .83 for the standard small-flame-ignition mockup test, .83 for the small-flame-ignition mockup/extra foam test, .95 for the full-scale cigarette-ignition test, and .59 for the standard cigarette-ignition mockup test. Excluding the mockup cigarette-ignition test, which included only 13 of the 27 chairs, the mean proportion of passes across the 27 chairs ranged from .74 to .95, reflecting a tendency for most chairs to pass most tests.

Table 1. Mean Proportion of Passes per Test

Test	Mean	SE	n	95% CI
Full-Scale Small-Flame-Ignition	.74	.07	27	(.59, .89)
Standard-Mockup Small-Flame-Ignition	.83	.07	27	(.68, .97)
UK Foam/Fabric-Mockup Small-Flame-Ignition	.83	.07	22	(.68, .98)
Full-Scale Cigarette-Ignition	.95	.03	27	(.90, 1.00)
Standard-Mockup Cigarette-Ignition	.59	.13	13	(.30, .88)

Note: 95% confidence intervals (CI) based on 1-sample *t* distribution.

If average pass-fail results are relatively close to 1.0 across a set of tested units, as in the present study, there is limited ability to assess the consistency of results across different tests for two reasons. First, although the tests all agree with average pass-fail results relatively near 1.0, it remains open how well, if at all, the tests would agree on a set of chairs containing a larger proportion of failures. In particular, some tests might pass many of the failing chairs, while others might not. Only by including a larger proportion of chairs known to fail at least one of the tests can this possibility be checked. Second, with average pass-fail results near 1.0 on a given test, there is little variation in results across chairs for that test, and thus, limited ability of that test to covary (i.e., correlate) with any other test. In the extreme case, if the average pass-fail result is exactly 1.0, there is no variation of the test results at all, and test results that do not vary cannot covary with anything. Exactly the same arguments apply if the tested units are mostly failures, although that was not a problem in the present study.

The optimal sample for assessing the consistency of different pass-fail tests on the same units includes a range of pass-fail results from 0.0 to 1.0, with an average proportion passing around 0.50, and with about half the sample below 0.50 and half above 0.50. This balanced spectrum of units from the worst performing to the best performing on a benchmark test, such as the full-scale *small-flame ignition* test, provides the best opportunity for comparison of different pass-fail tests on those units. If another test, such as the full-scale *cigarette ignition* test, exhibits a higher average proportion passing on the same set of units, and/or does not correlate with the benchmark test, then the former and latter tests are not consistent.

Assessment of differences in mean proportion passing and intercorrelations for the different tests reported below are problematic due to the selection of predominately passing chairs for testing in this study.

Differences in Mean Proportion of Passes

The statistical significance of each pairwise difference in mean proportion was assessed by a 2-tailed paired-samples *t*-test with $\alpha = .05$ both on untransformed and on arcsin-transformed data [1]; the same pattern of *p* values held for both sets of data, so results are presented for the untransformed data. None of the pairwise differences was significant among the 3 small-flame-ignition tests, but there were significant differences between the full-scale small-flame-ignition test and the full-scale cigarette ignition test $\{t(26) = 3.13\}$, and between the 2 cigarette-ignition tests $\{t(12) = 3.02\}$. The small number of standard-mockup cigarette-ignition test trials ($n = 13$) resulted in a very large 95% confidence interval for the mean proportion passing that test (.30, .88), and this, coupled with the limited variation of results for the full-scale cigarette-ignition test, precludes interpretation of the statistically significant difference between mean proportions passing the two cigarette ignition tests.

Test Intercorrelations

Table 2 gives Kendall Tau b (τ) correlations [2,3] assessing the consistency of test results across the 27 chairs, along with the corresponding sample sizes, average mean differences, standard errors of the mean differences, and 95% confidence intervals for the mean differences. The statistical significance of each correlation was assessed by a 1-tailed Z-test with $\alpha = .05$. The small-flame-ignition tests (full-scale = 1, standard mockup = 2, mockup with extra foam = 3) were positively intercorrelated, $\tau_{12} = .68$, $\tau_{13} = .41$, $\tau_{23} = .70$, indicating consistency of the small-flame-ignition results across the 27 chairs. In addition, the full-scale cigarette-ignition test (4) was positively correlated with the mockup cigarette-ignition test (5), $\tau_{45} = .66$. Although correlations of the cigarette-ignition full-scale and mockup tests with the 3 small-flame-ignition tests were all positive, ranging from .05 to .34, none was statistically significant; the small sample sizes and preponderance of proportions of 1.0 preclude interpretation of these nonsignificant correlations.

Table 2. Correlations, Sample Sizes, Mean Differences, Standard Errors, and 95% Confidence Interval

Tests Compared	τ	n	Mean Difference	SE Difference	95% CI Difference
1 vs. 2	.68*	27	-.090	.050	(-.193, .012)
1 vs. 3	.41*	22	-.133	.079	(-.298, .031)
1 vs. 4	.16	27	-.215*	.069	(-.356, -.074)
1 vs. 5	.05	13	.167	.165	(-.192, .525)
2 vs. 3	.70*	22	-.030	.065	(-.166, .106)
2 vs. 4	.07	27	-.125	.067	(-.262, .013)
2 vs. 5	.15	13	.179	.163	(-.175, .534)
3 vs. 4	.09	22	-.108	.067	(-.248, .032)
3 vs. 5	.34	12	.278	.141	(-.033, .588)
4 vs. 5	.66*	13	.333*	.110	(.093, .574)

Notes: * $p < .05$.

Tests are numbered as follows:

- 1 = Full-Scale Small-Flame-Ignition
- 2 = Standard-Mockup Small-Flame-Ignition
- 3 = UK Foam/Fabric-Mockup Small-Flame-Ignition
- 4 = Full-Scale Cigarette-Ignition
- 5 = Standard-Mockup Cigarette-Ignition

Pearson correlation coefficients computed for comparison with the Kendall Taus gave a similar pattern of results for the small-flame ignition intercorrelations, but indicated significant correlations of the full-scale cigarette ignition results with both the full-scale and extra-foam mockup small-flame ignition results. However, Pearson correlations are less appropriate than Kendall Tau correlations when the data contain a large proportion of ties, as in the present case where the majority of proportion passing scores were 1.0 (e.g., the average proportion correct in the full-scale cigarette ignition test was .95).

Discussion

Replications of the same test on the same fabric tended to be consistent as evidenced by a preponderance of pass proportions near 0 or 1 in the test data. In addition, correlational analyses revealed statistically significant intercorrelation of the 3 different small-flame-ignition tests (Tests 1, 2, and 3 in Table 2) and of the full-scale and mockup cigarette ignition tests (Tests 4 and 5 in Table 2). The small number of standard-mockup cigarette-ignition test trials ($n = 13$) precludes firm conclusions about the actual correlation of that test with the others.

Pairwise comparisons revealed no significant differences in mean proportion passing between the small-flame-ignition tests, with mean proportions passing ranging from .74 to .83. However, pairwise comparisons did reveal a significant difference in mean proportions passing between the full-scale cigarette-ignition test (mean = .95) and both the small-flame-ignition test (mean = .74) and the mockup cigarette-ignition test (mean = .59). The small number of standard-mockup cigarette-ignition test trials ($n = 13$) resulted in a very large 95% confidence interval for the mean proportion passing that test (.30, .88) which precludes interpretation of the statistically significant difference between mean proportions passing the two cigarette ignition tests. The large mean proportion correct in the full-scale cigarette ignition test (.95) implies very little variation in those proportions across the 27 UK chairs, and consequently, very little covariation (i.e., correlation) of that variable with the others. Assessments of the consistency of results across pass-fail tests are at best inefficient when average pass-fail results are close to either 0 or 1 as in the present case.

References

1. Kirk RE (1995). *Experimental Design: Procedures for the Behavioral Sciences* (3rd ed). Washington: Brooks/Cole.
2. Liebetrau AM (1983). *Measures of Association*. New York: Sage Publications.
3. Gibbons JD (1993). *Nonparametric Measures of Association*. New York: Sage Publications.

Appendix A

Proportion of Ignition Test Passes by Chair and Type of Test

Chair	Small-Ignition Tests			Cigarette-Ignition Tests	
	Full-Scale	Mockup	UK Foam	Full-Scale	Mockup
1	0.00	0.00	0.00	1.00	0.33
2	1.00	1.00	1.00	1.00	1.00
3	0.00	0.00	0.00	0.40	0.00
4	1.00	1.00	1.00	1.00	1.00
5	0.83	1.00	1.00	1.00	1.00
6	1.00	1.00	1.00	1.00	0.00
7	1.00	1.00		1.00	
8	0.50	0.67		1.00	
9	0.50	1.00	1.00	1.00	
10	0.00	0.00	1.00	1.00	1.00
11	1.00	1.00		1.00	1.00
12	0.33	1.00	1.00	0.70	
13	0.40	0.00	0.67	1.00	
14	0.83	1.00	1.00	1.00	
15	1.00	1.00	1.00	1.00	
16	1.00	1.00		1.00	
17	0.00	1.00	1.00	1.00	
18	1.00	1.00	1.00	1.00	
19	0.50	0.67	0.33	1.00	
20	1.00	1.00		1.00	
21	1.00	1.00	1.00	1.00	1.00
22	1.00	1.00	0.33	1.00	
23	1.00	1.00	1.00	1.00	
24	1.00	1.00	1.00	1.00	1.00
25	1.00	1.00	1.00	0.70	0.00
26	1.00	1.00	1.00	0.90	0.00
27	1.00	1.00	1.00	1.00	0.33
Mean	0.74	0.83	0.83	0.95	0.59
n	27	27	22	27	13
SE	0.07	0.07	0.07	0.03	0.13



United States
CONSUMER PRODUCT SAFETY COMMISSION
Washington, D.C. 20207

MEMORANDUM

DATE: October 2000

TO : Dale Ray, Project Manager Upholstered Furniture, Directorate for Economic Analysis

THROUGH: Andrew Stadnik, Associate Executive Director, Directorate for Laboratory Sciences
Warren Porter, Division Director, Chemistry, Laboratory Sciences *W. Porter*
Robert Garrett, Director, Electrical Engineering, Laboratory Sciences *R. Garrett*

FROM : David Cobb, Division of Chemistry, LSC *D. Cobb*
Weiying Tao, Division of Electrical Engineering, LSE *Weiying Tao*

SUBJECT : **IMPACT OF FLAME RETARDANT CHEMICALS, FILLING MATERIALS,
AND FABRIC TYPE ON FLAMMABILITY TESTING**

PURPOSE

This memorandum describes possible explanations for differences between full-scale and mockup small open flame test results for the United Kingdom (UK) chairs. Discussions on the possible reasons that some fabrics/chairs failed small open flame tests and cigarette ignition tests are also provided.

INTRODUCTION

Laboratory Sciences staff at the US Consumer Product Safety Commission conducted tests on 27 UK chairs to evaluate their resistance to small open flame ignition and cigarette ignition. The tests included full-scale and corresponding mockup tests for both open flame ignition and cigarette ignition¹. The referred study¹ concluded that:

- Eighty-one percent (22) of the 27 UK chairs had corresponding results in both full-scale and mockup seating area tests using standard foam. This indicates a reasonable correlation.
- Fifty-nine percent (16) of the 27 UK chairs did not ignite when tested to both the seating area full-scale and mockup protocols, which indicates manufacturing methods exist that can meet the draft standard requirements.
- Eighty-seven percent (14) of the 16 UK chairs resisting ignition in both seating area tests, also resisted ignition from cigarettes in full-scale tests. This indicates that chairs can be manufactured to resist ignition from both small open flame and cigarettes.

The relationship between the draft test protocol and the flammability performance of full-scale upholstered furniture indicated that at least 81% of the time there was a good correlation between the two. However in five cases there were differences between the small open flame full-scale and mockup test results. To better understand and explain these differences in test results, the video tapes of the full-scale and mockup tests were reviewed, additional mockup tests were conducted and more thorough chemical analyses of the flame retardant chemical backcoatings on these UK fabrics along with other upholstery fabrics treated with flame retardant chemicals were performed. The additional information gathered is presented in this memorandum.

METHODS

UK chairs 5, 9, 12, 14, and 17 failed full-scale small open flame tests, but passed open flame mockup tests using the standard foams. Due to the noted differences, several approaches were taken to extract more information to analyze the UK chair test results.

1. Further chemical analyses were performed to determine the level and the uniformity of the flame retardant chemical (FRC) treatments on the UK chairs.
 - a. All 27 UK chairs were previously analyzed to determine FRC content.³ The fabric samples were analyzed for hexabromocyclododecane (HBCD), decabromo diphenyl ether (DB), antimony (Sb), and phosphorus (P). Additional tests on 18 of the UK chair fabrics were performed to determine FRC variability. Two to six fabric specimens obtained from different locations on each chair were provided by LSE. Two aliquots from each specimen were collected and analyzed for FRC concentrations. Following this initial variability study, 5 of the 18 fabrics were selected for further analysis to determine FRC variability across a small section of fabric. The fabric specimens were obtained from the backs of the chairs. Ten aliquots from each of the 5 fabric specimens were collected and analyzed for FRC concentrations. The results of this variability study are provided and discussed in this report.
 - b. Additional FRC treated fabrics from the interlab study(IL fabrics) and other fabrics designated (UF) were analyzed to determine if similar correlations between FRC content and flammability testing noted for the UK fabrics were seen in these fabrics. The chemical analysis data and the flammability testing data for these fabrics are included in the evaluations discussed in this report.
2. Mockups using the actual filling materials from UK chairs 9, 12, 14, and 17 were constructed and tested according to the test protocol in the CPSC Staff's Draft Standard for Small Open Flame Ignition Resistance using the revised test fixture². UK chair 5 could not be utilized because not enough fabric was available.
3. Video tapes on the 27 UK chair tests were watched closely to observe the tests and evaluate visual indications and characteristics of ignition performance.

RESULTS AND DISCUSSION

Fabric FRC Results

Immersion Treated Fabrics

The FRC treatment used for the four immersion treated UK fabrics is phosphonic acid, (3-[[hydroxymethyl]amino], dimethyl ester. Direct analysis of this chemical in the fabric is not possible. This chemical does contain P which can be easily analyzed using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP) following acid digestion³.

Previous studies reported⁴ that some of the P found in fabrics using this FRC treatment is due to the presence of residual phosphate ions. The amount of phosphate ions present was determined by high pressure liquid chromatography (HPLC)⁴.

Phosphorus results for the four UK chairs ranged from 1.2 to 1.5 %. Phosphorus results from within each specimen and each chair did not vary very much. The relative standard deviation (RSD) of P for each of the four fabrics was less than 6%. The amount of phosphate P ranged from 0.035 to 0.098%. This represents only 2.7 to 8.0% of the total P. The P results for the UK chairs are provided in tables 1 and 2.

Table 1. Variability, Results of Analysis, Phosphorus, P

Chair No.	Specimen/ Sample No.	Description/ Location	Mg of P per cm ² of fabric	% P	Specimen Avg P %	Specimen %RSD	Fabric Avg P %	Fabric %RSD
UK24	1a	Seat	0.404	1.253	1.26	0.68	1.22	2.61
	1b		0.407	1.265				
	2a	Back	0.385	1.196	1.20	0.86		
	2b		0.390	1.211				
	3a	Side	0.382	1.185	1.20	1.62		
	3b		0.390	1.213				
UK25	1a	Seat	0.628	1.480	1.47	1.16	1.42	5.54
	1b		0.617	1.456				
	2a	Back	0.542	1.279	1.34	6.72		
	2b		0.596	1.407				
	3a	Outside Back	0.635	1.497	1.46	4.03		
	3b		0.600	1.414				
UK26	1a	Seat	0.512	1.348	1.30	5.55	1.34	4.22
	1b		0.474	1.246				
	2a	Back	0.505	1.328	1.35	2.19		
	2b		0.521	1.370				
	3a	Side	0.539	1.419	1.38	3.68		
	3b		0.512	1.347				
UK27	1a	Seat	0.318	1.343	1.32	3.07	1.30	2.57
	1b		0.305	1.287				
	2a	Back	0.298	1.258	1.27	0.89		
	2b		0.302	1.274				
	3a	Side	0.313	1.321	1.32	0.17		
	3b		0.314	1.324				

Notes: 1. Specimen/Sample No. = Each swatch of fabric was assigned a number 1-3, two samples were cut from each specimen and designated either a or b. 2. Avg = average, RSD = relative standard deviation

Table 2.
Phosphate, HPLC Analysis

Chair No.	Specimen No.	Description/ Location	% Phosphate	% Phosphate as P
UK 24	1	Seat	0.30	0.10
	2	Back	0.25	0.08
	3	Side	0.29	0.09
UK 25	1	Seat	0.28	0.09
	2	Back	0.27	0.09
	3	Outside Back	0.24	0.08
UK 26	1	Seat	0.23	0.07
	2	Back	0.25	0.08
	3	Side	0.23	0.07
UK 27	1	Seat	0.11	0.04
	2	Back	0.11	0.03
	3	Side	0.11	0.04

Estimated FRC P
Total P – Phosphate P

Chair No.	Specimen No.	Description/ Location	Estimated FRC P%	Avg FRC P%	Estimated FRC%	Estimated FRC% Avg
UK 24	1	Seat	1.16	1.13	7.90	7.69
	2	Back	1.12		7.62	
	3	Side	1.11		7.56	
UK 25	1	Seat	1.38	1.34	9.39	9.12
	2	Back	1.25		8.51	
	3	Outside Back	1.38		9.39	
UK 26	1	Seat	1.23	1.27	8.37	8.64
	2	Back	1.27		8.64	
	3	Side	1.31		8.92	
UK 27	1	Seat	1.28	1.27	8.71	8.64
	2	Back	1.24		8.44	
	3	Side	1.28		8.71	

Note: FRC = Phosphonic acid, (3-[[hydroxymethyl]amino]-3-oxopropyl)-, dimethyl ester, C₆H₁₄O₅NP
Molecular weight is 211. Atomic weight of P is 31. Calculations as follows:
FRC P% = Total P – Phosphate P
FRC% = FRC P% X (211/31)

Backcoated Fabrics

All of the backcoated fabrics contained Sb. Sb was analyzed using ICP. In addition most of these fabrics contained either DB or HBCD. DB and HBCD were analyzed using HPLC.

The Sb results for the fabrics tested in the variability study ranged from 0.3 to 4.2%. Sb results from within each specimen and each chair generally did not vary very much. The RSD of the Sb for most of the fabrics and specimens was less than 10%. Fabric specimens from UK12 however, varied the most with an RSD for Sb of 42%. The Sb results are contained in table 3.

Table 3. Variability, Results of Analysis, Antimony, Sb

Chair No.	Specimen/ Sample No.	Description/ Location	% Sb	Specimen Avg Sb %	Specimen %RSD	Fabric Avg Sb %	Fabric %RSD
UK1	1a	Back	0.559	0.56	0.13	0.55	2.50
	1b		0.560				
	2a	Seat	0.558	0.55	2.19		
	2b		0.541				
	3a	Side	0.566	0.55	4.64		
	3b		0.530				
UK5	1a	Side	2.861	2.86	0.05	2.86	1.63
	1b		2.859				
	2a	Side	2.814	2.86	2.08		
	2b		2.898				
	3a	Side	2.908	2.85	2.98		
	3b		2.788				
UK6	1a	Seat	1.128	1.11	1.97	1.10	5.59
	1b		1.097				
	2a	Back	1.093	1.10	0.32		
	2b		1.098				
	3a	Side	1.023	1.04	1.78		
	3b		1.049				
	1	Back 2 nd Set	1.109	1.12	6.29		
	2		1.160				
	3		1.125				
	4		1.144				
	5		1.070				
	6		1.264				
	7		1.168				
	8		1.086				
	9		1.044				
	10		1.021				
UK8	1a	Back	1.822	1.85	2.14	1.84	5.60
	1b		1.878				
	2a	Back	1.803	1.81	0.70		
	2b		1.821				
	3a	Seat	1.857	1.75	8.90		
	3b		1.637				
	4a	Side	1.834	1.82	0.81		
	4b		1.813				
	5a	Side	2.057	1.98	5.83		
	5b		1.894				

Table 3. Continued
Variability, Results of Analysis
Antimony, Sb

Chair No.	Specimen/ Sample No.	Description / Location	% Sb	Specimen Avg Sb %	Specimen %RSD	Fabric Avg Sb %	Fabric %RSD
UK9	1a	Side	0.578	0.56	5.73	0.56	2.23
	1b		0.533				
	2a	Side	0.577	0.57	2.24		
	2b		0.559				
	3a	Back	0.563	0.56	0.12		
	3b		0.564				
	1	Back 2 nd Set	0.568	0.56	2.23		
	2		0.565				
	3		0.564				
	4		0.575				
	5		0.548				
	6		0.568				
	7		0.559				
	8		0.552				
	9		0.548				
	10		0.545				
UK11	1a	Back	1.023	1.06	5.58	1.05	2.72
	1b		1.107				
	2a	Back	1.053	1.05	0.47		
	2b		1.046				
	3a	Back	1.067	1.05	2.02		
	3b		1.037				
	4a	Side	1.048	1.03	2.26		
	4b		1.015				
UK12 Rust	1a	Side	0.952	0.95	0.37	0.96	2.27
	1b		0.947				
	2a	Side	0.994	0.97	2.98		
	2b		0.953				
UK12 Plaid	3a	Back	0.729	0.75	3.96	0.87	41.6
	3b		0.771				
	4a	Back	0.562	0.55	2.43		
	4b		0.543				
	5a	Seat	1.500	1.47	3.13		
	5b		1.435				
	6a	Unknown	1.545	1.50	4.05		
	6b		1.459				

Table 3. Continued
Variability, Results of Analysis
Antimony, Sb

Chair No.	Specimen/ Sample No.	Description / Location	% Sb	Specimen Avg Sb %	Specimen %RSD	Fabric Avg Sb %	Fabric %RSD
UK12 Plaid	1	Back 2 nd Set	0.606	0.71	22.3	0.87	41.6
	2		0.667				
	3		0.679				
	4		0.848				
	5		0.819				
	6		0.712				
	7		0.612				
	8		0.570				
	9		0.547				
	10		1.065				
UK13	1a	Back	2.415	2.44	1.62	2.44	8.10
	1b		2.471				
	2a	Back	2.474	2.37	6.42		
	2b		2.259				
	3a	Seat	2.299	2.26	2.34		
	3b		2.224				
	4a	Side	2.223	2.38	9.44		
	4b		2.541				
	5a	Side	2.278	2.25	1.92		
	5b		2.217				
	1	Back 2 nd Set	2.731	2.55	8.23		
	2		2.652				
	3		2.216				
	4		2.374				
	5		2.318				
	6		2.461				
	7		2.711				
	8		2.492				
	9		2.888				
	10		2.620				
UK14	1a	Seat	4.815	4.54	8.42	4.21	12.9
	1b		4.274				
	2a	Back	3.954	4.30	11.3		
	2b		4.640				
	3a	Side	4.277	3.78	18.6		
	3b		3.285				

**Table 3. Continued, Variability, Results of Analysis
Antimony, Sb**

Chair No.	Specimen/ Sample No.	Description / Location	% Sb	Specimen Avg Sb %	Specimen %RSD	Fabric Avg Sb %	Fabric %RSD
UK17	1a	Back	1.650	1.60	4.10	1.53	6.82
	1b		1.557				
	2a	Back	1.368	1.44	6.93		
	2b		1.509				
	3a	Back Outside	1.624	1.55	7.14		
	3b		1.468				
UK18	1a	Back	3.443	3.56	4.67	3.56	7.34
	1b		3.678				
	2a	Seat	3.853	3.56	11.8		
	2b		3.258				
UK19	1a	Back	0.301	0.29	5.36	0.30	4.76
	1b		0.279				
	2a	Back	0.291	0.29	1.97		
	2b		0.283				
	3a	Seat	0.313	0.31	1.60		
	3b		0.306				
	4a	Seat	0.320	0.31	3.86		
	4b		0.303				
UK21	1a	Seat	1.739	1.68	5.05	1.92	16.8
	1b		1.619				
	2a	Back	1.865	1.70	14.0		
	2b		1.528				
	3a	Side	1.802	1.96	11.7		
	3b		2.128				
UK22	1a	Back	2.266	2.36	5.43	2.36	4.94
	1b		2.447				
	2a	Seat	2.214	2.14	4.65		
	2b		2.073				
	3a	Side	2.330	2.37	2.56		
	3b		2.416				
	1	Back 2 nd Set	2.336	2.40	3.45		
	2		2.348				
	3		2.266				
	4		2.467				
	5		2.442				
	6		2.480				
	7		2.334				
	8		2.373				
	9		2.532				
	10		2.447				

Fabric specimens from eleven backcoated chairs contained DB. The DB results ranged from 1.2 to 11.0%. DB results from within each specimen and each chair generally had an RSD of less than 15%. The DB results are contained in table 4.

Table 4. Variability, Results of Analysis, Decabromo Diphenyl Ether, DB

Chair No.	Specimen/ Sample No.	Description/ Location	% DB	Specimen Avg DB %	Specimen %RSD	Fabric Avg DB %	Fabric %RSD
UK5	1a	Side	7.395	7.61	4.06	7.05	7.40
	1b		7.832				
	2a	Side	6.807	6.62	3.99		
	2b		6.433				
	3a	Side	7.195	6.92	5.70		
	3b		6.637				
UK8	1a	Back	4.872	4.76	3.21	4.36	8.40
	1b		4.656				
	2a	Back	4.024	4.06	1.31		
	2b		4.099				
	3a	Seat	3.746	3.88	5.03		
	3b		4.023				
	4a	Side	4.607	4.52	2.67		
	4b		4.437				
	5a	Side	4.477	4.58	3.28		
	5b		4.690				
UK9	1a	Side	2.676	2.84	8.25	3.06	8.20
	1b		3.008				
	2a	Side	3.086	2.99	4.69		
	2b		2.888				
	3a	Back	2.676	2.65	1.24		
	3b		2.629				
	1	Back 2 nd set	3.554	3.20	4.94		
	2		3.317				
	3		3.138				
	4		3.336				
	5		3.076				
	6		3.197				
	7		3.025				
	8		3.102				
	9		3.107				
	10		3.188				
UK11	1a	Back	4.582	4.81	6.63	4.70	6.08
	1b		5.032				
	2a	Back	4.772	4.71	1.84		
	2b		4.650				
	3a	Back	5.125	4.84	8.23		
	3b		4.561				
	4a	Side	4.656	4.43	7.07		
	4b		4.213				

Table 4. Continued
Variability, Results of Analysis
Decabromo Diphenyl Ether, DB

Chair No.	Specimen/ Sample No.	Description/ Location	% DB	Specimen Avg DB %	Specimen %RSD	Fabric Avg DB %	Fabric %RSD
UK13	1a	Back	2.607	2.98	17.5	3.24	13.3
	1b		3.345				
	2a	Back	2.864	3.37	21.3		
	2b		3.878				
	3a	Seat	3.413	3.01	18.8		
	3b		2.612				
	4a	Side	3.007	3.11	4.85		
	4b		3.221				
	5a	Side	2.694	3.07	17.4		
	5b		3.451				
	1	Back 2 nd Set	3.610	3.37	12.37		
	2		3.716				
	3		3.245				
	4		2.751				
	5		2.857				
	6		4.150				
	7		3.299				
	8		3.269				
	9		3.638				
	10		3.193				
UK14	1a	Seat	7.762	7.85	1.62	8.95	25.0
	1b		7.941				
	2a	Back	7.711	7.64	1.37		
	2b		7.563				
	3a	Side	13.29	11.4	24.2		
	3b		9.407				
UK17	1a	Back	6.874	6.38	10.9	6.64	6.26
	1b		5.893				
	2a	Back	7.087	6.86	4.76		
	2b		6.625				
	3a	Back	6.534	6.69	3.28		
	3b		6.844				
UK18	1a	Back	10.96	10.7	3.74	10.5	5.05
	1b		10.40				
	2a	Seat	10.88	10.4	7.32		
	2b		9.811				

Table 4. Continued
Variability, Results of Analysis
Decabromo Diphenyl Ether, DB

Chair No.	Specimen/ Sample No.	Description / Location	% DB	Specimen Avg DB %	Specimen %RSD	Fabric Avg DB %	Fabric %RSD
UK19	1a	Back	1.292	1.31	2.05	1.24	14.3
	1b		1.330				
	2a	Back	0.911	1.14	28.2		
	2b		1.366				
	3a	Seat	1.243	1.31	6.75		
	3b		1.368				
	4a	Seat	1.393	1.21	21.3		
	4b		1.028				
UK21	1a	Seat	9.589	8.87	11.4	7.62	15.5
	1b		8.156				
	2a	Back	6.523	6.55	0.53		
	2b		6.572				
	3a	Side	7.919	7.44	9.09		
	3b		6.962				
UK22	1a	Back	12.02	12.2	2.58	11.0	11.4
	1b		12.47				
	2a	Seat	11.43	11.1	3.90		
	2b		10.82				
	3a	Side	11.57	11.6	0.18		
	3b		11.54				
	1	Back 2 nd Set	11.14	10.6	13.3		
	2		11.23				
	3		11.11				
	4		10.22				
	5		10.46				
	6		7.896				
	7		13.31				
	8		9.311				
	9		10.18				
	10		11.01				

Fabric specimens from three of the chairs tested in the variability study contained HBCD. The HBCD results ranged from 5.9 to 11.6 %. Fabric specimens from UK12 varied the most with an RSD for HBCD of 25%. HBCD results are contained in table 5. Figure 1 shows where aliquots were obtained for UK12, and how the FRC varied across this fabric. Each aliquot was taken about 2-3 inches apart. Within this small section of fabric large variations in FRC were noted.

Table 5. Variability, Results of Analysis, Hexabromocyclododecane, HBCD

Chair No.	Specimen/ Sample No.	Description/ Location	% HBCD	Specimen Avg HBCD %	Specimen %RSD	Fabric Avg HBCD %	Fabric %RSD
UK1	1a	Back	5.014	5.65	15.9	5.94	8.41
	1b		6.288				
	2a	Seat	6.093	6.01	1.96		
	2b		5.927				
	3a	Side	6.433	6.16	6.24		
	3b		5.889				
UK6	1a	Seat	11.81	11.8	0.20	11.6	6.37
	1b		11.85				
	2a	Back	11.91	11.4	6.42		
	2b		10.88				
	3a	Side	10.35	10.5	2.20		
	3b		10.68				
	1	Back 2 nd Set of 10	11.57	11.8	6.18		
	2		11.83				
	3		13.15				
	4		11.86				
	5		12.41				
	6		12.05				
	7		11.59				
	8		10.56				
	9		11.74				
	10		10.86				
	UK12 Rust	1a	Side	6.488	6.47		
1b		6.457					
2a		Side	5.821	6.23	9.26		
2b			6.637				
UK12 Plaid	3a	Back	8.415	10.7	30.2	8.31	24.8
	3b		12.98				
	4a	Back	5.995	6.07	1.76		
	4b		6.146				
	5a	Seat	10.26	10.3	0.79		
	5b		10.38				
	6a	Unknown	10.23	9.81	6.00		
	6b		9.396				
	1	Back 2 nd Set	6.401	7.58	20.61		
	2		7.842				
	3		7.638				
	4		8.256				
	5		7.589				
	6		7.561				
	7		6.887				
	8		6.596				
	9		5.638				
10	11.43						

The average FRC levels found for each of UK fabrics including those not tested in the variability study are contained in table 6. The FRC results for the IL and UF fabrics are contained in table 7. A total of 43 backcoated fabrics have been analyzed for FRC content. Three of the 43 fabrics contained Sb but did not contain HBCD or DB.

Table 6. Averaged FRC Results for all UK Fabrics

Sample	Sb %	DB %	HBCD %	Phosphorus %
UK1 Chair	0.55		5.9	
UK2 Chair	2.12	6.6		
UK3 Chair, Rust	0.63		5.0	
UK3 Chair, Plaid	1.11	5.1		
UK4 Chair	3.71	8.3		
UK5 Chair	2.86	7.0		
UK6 Chair	1.11		11.6	
UK7 Chair	1.81	6.4		
UK8 Chair	1.84	4.4		
UK9 Chair	0.56	3.1		
UK10 Chair	0.0	0	0	
UK11 Chair	1.05	4.7		
UK12 Chair, Rust	0.96		6.3	
UK12 Chair, Plaid	0.87		8.3	
UK13 Chair	2.44	3.2		
UK14 Chair, Pink- Blue	4.21	8.9		
UK15 Chair	2.02	4.3		
UK16 Chair	2.20	9.5		
UK17 Chair	1.53	6.6		
UK18 Chair	3.56	10.5		
UK19 Chair	0.30	1.2		
UK20 Chair	1.86	7.5		
UK21 Chair	1.92	7.6		
UK22 Chair	2.36	10.9		
UK23 Chair	3.28	0	0	
UK24 Chair				1.22
UK25 Chair				1.42
UK26 Chair				1.34
UK27 Chair				1.30

Table 7. FRC Results for Other Fabrics Tested

Sample	Sb %	DB %	HBCD %	Phosphorus %
IL5	2.84	6.2		
IL7	2.57	6.5		
IL8	1.97	3.8		
IL9	3.71	6.5		
UF1	2.84	4.1		
UF2	1.93	0	0	
UF6	1.56	9.2		
UF7	1.93	12.0		
UF8	3.15		8.9	
UF9	1.86	4.8		
UF10	2.02	0	0	
UF17	3.01	6.1		
UF21	2.23	13.7		
UF24	2.04	11.4		
UF25	1.77	11.9		
UF26	1.76	8.8		
UF27	1.87	10.1		
UF28	1.91	4.5		
UF30	1.82	3.2		
UF31	2.31	4.5		
UF11				1.62
UF12				1.43
UF13				1.22
UF14				1.10
UF15				1.02
UF16				1.18
UF29				1.22
UF32				1.42

Relation of Amount of FRC in Upholstery Fabrics to Small Open Flame Flammability Results

The backcoated fabrics that failed the small open flame tests tended to have lower concentrations of FRC. Graphical representations of this are provided in figures 2-7. The trend lines depicted in the graphs for passing and failing flammability tests were obtained by visually looking at the plots of the data. These trend lines should not to be taken in the absolute sense. They are presented merely to show that fabrics with higher FRC levels generally perform better in the small open flame flammability tests. A precise minimum FRC threshold for passing the small open flame tests can not be determined from this limited study.

HBCD/Sb backcoated

Figures 2 and 3 illustrate the relation of HBCD and Sb toward small open flame flammability tests. UK6 was the only fabric that passed both full-scale and mockup tests. This fabric also contained the highest FRC levels. UK1 and UK3 failed both full scale and mock up tests, and these fabrics had the lowest FRC levels. UK12 had FRC levels in between and passed the mockup tests but failed the full scale tests. UK12 also had a large FRC variability as depicted in figure 4. The marginal FRC levels and the extreme FRC variability across the fabric appear to be major factors in UK12 failures in the full-scale tests.

DB/Sb backcoated

Figures 5 and 6 illustrate the relation of DB and Sb toward small open flame flammability tests. UK5 was the only fabric that had FRC levels above the pass trend line but failed a full-scale test by flame. UK5 failed only 1 of 6 tests, and failed where the fabric was loose fitting over the chair. The five UK fabrics that failed both full-scale and mockup tests had FRC below the "pass" trend line. Two of these fabrics had FRC levels below the "fail" trend line. Two of the UK fabrics that failed full-scale, but passed the mockup tests, UK9 and UK17 also had FRC levels below the "pass" trend line.

Four fabrics that had FRC levels above the "pass" trend line had failures on the mockup tests. IL9 was a thick weave sample that only failed by glow or smoke present at 2 minutes. UF27 self extinguished, but flames on 1 of the 2 tests conducted reached the top of the mockup before 2 minutes. UF26 failed in 2 of 2 tests by flame, but this fabric is 100% cellulosic and the FRC levels are just above the "pass" trend line. UF6 failed 1 of 3 tests by flame, but this fabric also is 100% cellulosic with FRC levels just above the "pass" trend line. Cellulosic fabrics may require higher FRC levels than thermoplastics or thermoplastic/cellulosic blends. Figure 7 illustrates the results of only the cellulosic fabrics tested.

Immersion Treated

Four of the UK chair fabrics and eight of the UF fabrics were immersion treated. The four immersion treated UK fabrics passed both full scale and mockup small open flame tests. The UF fabrics were only tested on the mockup, and all eight passed. Since there were no failures a relationship between the amount of immersion treatment and small open flame flammability test results could not be drawn.

Factors Other Than FRC That May Affect Open Flame Mockup Tests vs. Open Flame Full-Scale Tests

The inconsistencies between the mockup and full-scale small open flame tests for the five UK chairs were not totally unexpected because several major differences exist between the full-scale chairs/full-scale chair tests and the mockups/mockup tests. These major differences are:

- 1) The type of filling materials: Standard foam was used in the original set of mockup tests following the draft standard. However, the filling materials found in the full-scale chairs were generally polyester fiberfill and FR treated foams with the fiberfill directly beneath the upholstery fabrics in most cases. Previous studies⁵ indicated that filling materials used in mockup tests affected fabric flammability performance in some cases.
- 2) Chair design or geometry: In general, full-scale chairs were more curved than the mockup constructions. Limited observations suggest that flame spread over curved locations on upholstered chairs initially grows slowly but over time can accelerate, thus influencing ignition results⁶.
- 3) Number of tests: Six tests were performed on each full-scale chair (three tests on back/seat junction and three on side/seat junction). Three tests were performed on each mockup. The small number of flame applications per chair location or mockup increases the possibility that the current testing protocol may not adequately identify borderline fabrics, which sometimes resist ignition and other times ignite.

Test results of mockups using the actual filling materials are shown in Table 8. Fabric content/structure, weight, finish, filling materials, full-scale and standard foam mockup test results for the five chairs are also listed in this table. Mockup tests using the actual filling materials are better able to predict the full-scale chair tests than the mockup tests using the standard foams. This indicates that the filling materials used under the upholstery fabrics may influence the upholstery fabric flammability performance of some fabrics. This is consistent with other studies⁵.

Table 8. Comparison of Full Scale and Mockup Open Flame Tests for the Five UK Chairs

Chair No.	Fabric Content/Structure	Fabric Wt (oz/yd ²)	Filling Materials/Amount and Type of FR	Full Scale Results	Mockup Results	
					Std. foam	Actual Filling
UK 5	thermoplastic/cellulosic pile weave	10.5	b – fiberfill/none detected st – fiberfill/none detected, foam/0.72% P, 11.57% melamine s – fiberfill/none detected, foam/0.99% P, 13.78% melamine	I (1/6)	N (3/3)	---
UK 9	thermoplastic/cellulosic flopped pile	7.3	b – fiberfill/none detected, fiberfill/none det. st – fiberfill/none detected, foam/1.04% P, 1.33% melamine s – fiberfill/ none detected, foam/0.24% P, 9.80% melamine	I (3/6)	N (3/3)	I (1/6)
UK 12	a. cellulosic dobby weave b. cellulosic twill weave	a. 9.5 b. 7.7	b – fiberfill/none detected st – fiberfill/none detected s – foam/0.80% P, 14.89% melamine	I (4/6) a.(1/3) b.(3/3)	a. N (3/3) b. N (3/3)	b. N (3/3) b. I (3/3)
UK 14	thermoplastic/cellulosic jacquard pile weave	16.7	b – fiberfill/none detected st – foam/0.92% P, 0.87% melamine s – foam/0.54% P, 14.55% melamine	I (1/6)	N (3/3)	N (3/3)
UK 17	cellulosic/thermoplastic jacquard weave	12.5	b – fiberfill/none detected, foam/0.02% P, 14.18% melamine st – fiberfill/none detected, foam/0.43% P, 1.99% melamine s – airgap	I (6/6)	N (3/3)	I (3/3)

Small Open Flame Test Criteria: Glow/smoke at 2 minutes may not adequately represent flammability hazards. UK14 had only one failure with smoke at 150 seconds before self extinguishing. Additional testing of IL8 and IL9 showed these fabrics that failed the 2 minute criteria due to glow/smoke eventually self extinguished in 5 of 6 tests. The current British Standard⁸, extended the glow/smoke pass time to 15 minutes.

Discussion of the Five UK Chairs With Different Full-Scale vs Mockup Small Open Flame Test Results

- UK Chair No.5

This chair failed only 1 of 6 full-scale tests. A mockup using the standard foam did not ignite with three flame applications. Video tape on the chair test showed that the one failure during full-scale tests occurred where the flame was applied at a loose, wrinkled fabric location on the chair. Therefore, this one ignition may be attributed to the fabric's loose fitting over the chair in that particular area. The FRC levels of this fabric are well above the pass trend line as shown in Figures 6-7.

- UK Chair No.9

There were three ignitions out of six flame applications on the full-scale chair. The FRC levels for this fabric were 0.56% Sb and 3.1% DB as shown in Table 6. This is well below the "pass" trendlines depicted in figures 5 and 6. Mockups made with standard foams did not ignite during three flame applications. However, one ignition occurred during six flame applications on mockups made with actual filling materials (Table 8). UK9 is a highly curved chair with polyester fiberfill directly beneath the upholstery fabric. Previous research indicated that polyester fiber batting may contribute to the ignition of some upholstered furniture⁷. Curved design could influence fabric flammability performance as well⁶. These factors appear to be the cause for the inconsistencies between full-scale and mockup tests.

- UK Chair No.12

UK12 has two different fabrics on the side and the back (called fabrics "a" and "b" respectively). Only one ignition resulted from three flame applications in the full-scale tests on the side/seat junction vs. three ignitions on back/seat junction. Mockups constructed with standard foam and both fabrics a and b did not ignite. However, a mockup constructed with chair back fabric (fabric b) and actual filling materials from the chair ignited during all three flame applications. The FRC levels for this fabric varied greatly as shown in figures 1 and 4, and the levels were generally below the "pass" trendline. The marginal FRC levels and the filling materials in the chair appear to be the cause for the inconsistencies between full-scale and mockup tests.

- UK Chair No.14

There was only one ignition out of six flame applications on full-scale UK14 and the recorded event was due to smoke only, which self-extinguished at 150 seconds. This could be a pass if a glow/smoke duration time longer than 2 minutes is allowed in the test criteria. All mockups did not ignite during three flame applications. The FRC levels of this fabric are well above the pass trend line as shown in Figures 6-7.

- UK Chair No.17

As shown in table 6, UK17 had FRC levels of 1.53% Sb and 6.6% DB. As shown in figures 5 and 6 this is slightly below the “pass” trendline. Polyester fiberfill and treated foams were used as the filling materials for the chair back, and there was no filling material on the chair side (air gap only). There were six ignitions (all ignited) out of six flame applications (three on the side and three on the back) on the full-scale chair. Three failures on the side/seat junction were due to smoke only. There were no ignitions on the mockups constructed with the standard foams. However, a mockup constructed with the actual filling materials ignited every time with three flame applications applied. As discussed earlier, filling materials could influence the upholstered chair flammability performance when the upholstery fabric used had marginal FRC levels.

Fabrics/Chairs That Failed Both Full-Scale and Mockup Small Open Flame Tests

UK1, UK3, UK8, UK10, UK13, and UK19 failed both full scale and mock up tests. These chairs did not resist small open flame ignition likely because of low FRC levels on the fabrics. The FRC levels for these chairs are all below the “pass” trend line as depicted in figures 2-6.

Relation of Fabric FRC Results to Cigarette Flammability Results

Backcoated Fabrics

Figures 8 and 9 depict FRC results in relation to cigarette testing. All of the DB/Sb backcoated chairs with the exception of UK3 passed the cigarette testing. UK3 consisted of 2 fabrics, one was treated with DB while the other was treated with HBCD. The HBCD treated fabric was also cellulosic. The fabrics for the rest of the DB treated fabrics were either thermoplastics or thermoplastic/cellulosic blends. All of the HBCD treated fabrics failed either mockup or full-scale cigarette testing. All of the HBCD fabrics were 100% cellulosic. UK6, the only HBCD treated fabric that performed well in the small open flame tests, passed full-scale cigarette testing but failed the mockup tests. The filling material in the back, seat and side of the UK6 chair consisted of flame retardant(FR) foam. FR foam may be the reason that UK6 passed full-scale but failed mockup. Fabric type and filling material seem to be more important factors in passing cigarette testing than FRC levels in the fabric.

Immersion Treated

Two of the immersion treated UK fabrics were 100% cellulosic, while the other two were cellulosic/thermoplastic blends. The two cotton fabrics, UK25 and UK27, both failed the mockup cigarette tests, but only UK25 failed the full-scale tests. The filling material in the back and seat of UK25 consisted of feathers, while the filling material in UK27 consisted of fiberfill and FR foam. FR foam may be the reason UK27 passed full-scale but failed mockup cigarette testing.

UK24 and UK26 were both cellulosic/thermoplastic blends. UK24 passed both full-scale and mockup cigarette tests, while UK26 failed both. The filling materials for both were similar, but UK26 had feathers in both the back and seat while UK24 had feathers in only the seat. The slight differences in filling material may be a contributing factor in the full scale tests. However, UK26 also failed the mockup cigarette test while UK24 passed the mockup. Since the filling material is the same for the mockup test, differences in the fabric must be a factor. The amount of thermoplastics and FRC found in both fabrics are similar, but UK26 fabric has a pile structure versus the plain structure of UK24. UK26 is also a heavier fabric 11.2 oz/yd² versus 9.5 oz/yd² for UK24. These slight structural differences in the fabric may be contributing factors for the failure of UK26 in both the cigarette tests.

Although the FRC, phosphonic acid (3-{{[hydroxymethyl]amino}dimethyl ester, can not be measured directly, concentrations can be inferred from P analysis. The four immersion treated UK fabrics contained similar P levels, but only one of the fabrics, UK24 passed all cigarette testing. UK24 actually had slightly lower P levels than the other three fabrics. Fabric type and filling material seem to be more important factors in passing cigarette testing than FRC levels in the immersion treated fabrics.

CONCLUSIONS

The following conclusions are made from this evaluation:

- Eighty-one percent, 22 of the 27 UK chairs have the same small open flame flammability results when tested full-scale or mockup using the current draft test protocol⁴. If the glow/smoke criteria is changed to 15 minutes, eighty-five percent, 23 of the 27 UK chairs, would have the same full scale and mockup results. Testing has shown that some of the fabrics that have glow/smoke at 2 minutes will eventually self extinguish. The final test protocol should allow for a longer observation time, such as 15 minutes for glow/smoke.
- The amount of FRC in backcoated fabrics is an important factor in the tendency of a fabric to pass the small open flame tests. Fabrics with marginal FRC levels may pass mockup tests but fail full-scale depending on such factors as filling materials and chair construction. If a criteria for minimum FRC in the fabrics was established, 3 of the 4 remaining fabrics that passed mockup but failed full-scale may have been successfully screened. An exact minimum criteria for FRC can not be made from this study, but the levels are likely to be at or above the "pass" trendlines noted in figures 2-9. Factors such as fabric type and filling materials used need to be considered when determining minimum FRC requirements. Cellulosic fabrics may require more FRC in the backcoating than thermoplastics.
- FR foam or more flame resistant filling materials may be required with cellulosic fabrics in order to pass cigarette tests.

- As shown in the data, there are chairs on the UK market that pass both small open flame and cigarette flammability tests.

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4. Memorandum to Treye Thomas, Health Sciences, from D. Cobb, LSC *Migration Study of Flame Retardant Chemicals from Children's Sleepwear*, June 2000, CPSC
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7. Damant, G., McCormack, J., Wortman, P., and Hilado, C., The California Technical Bulletin 133 Test: Some Background and Experience, undated.
8. BS5852, *Assessment of the ignitability of upholstered seating by smouldering and flaming ignition sources*, 1990, British Standards Institution

UK12 Photo

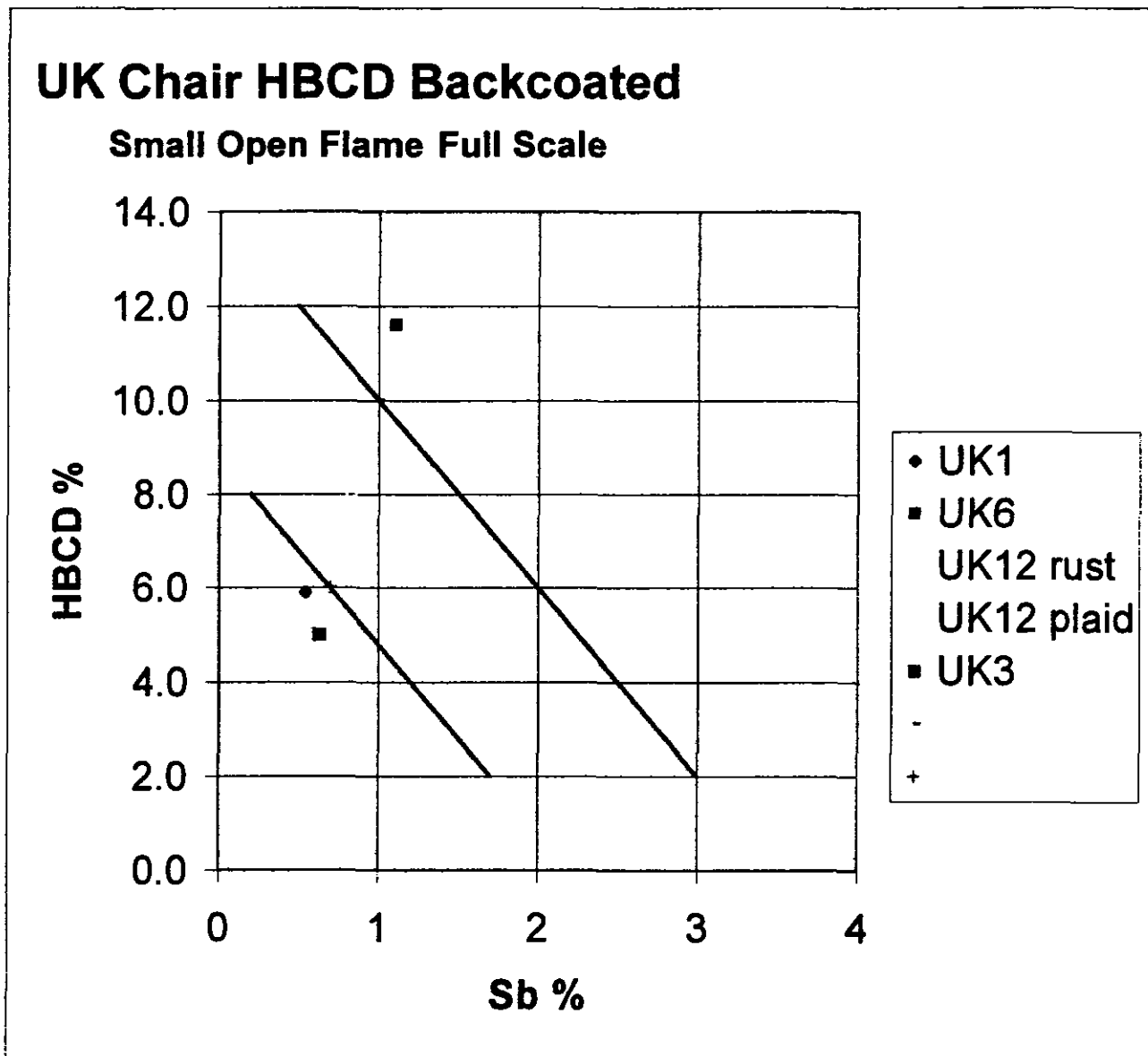


Figure 1.

Sample #	Sb	HBCD	
UK1	0.55	5.9	Average of 6
UK3	0.63	5.0	Average of 2
UK6	1.11	11.6	Average of 15
UK12 rust	0.96	6.3	Average of 4
UK12 plaic	0.83	8.1	Average of 16

Relationship of Sb and HBCD to full-scale small open flame testing is depicted below

This graph shows that as FRC levels increased the tendency for passing small open testing increased



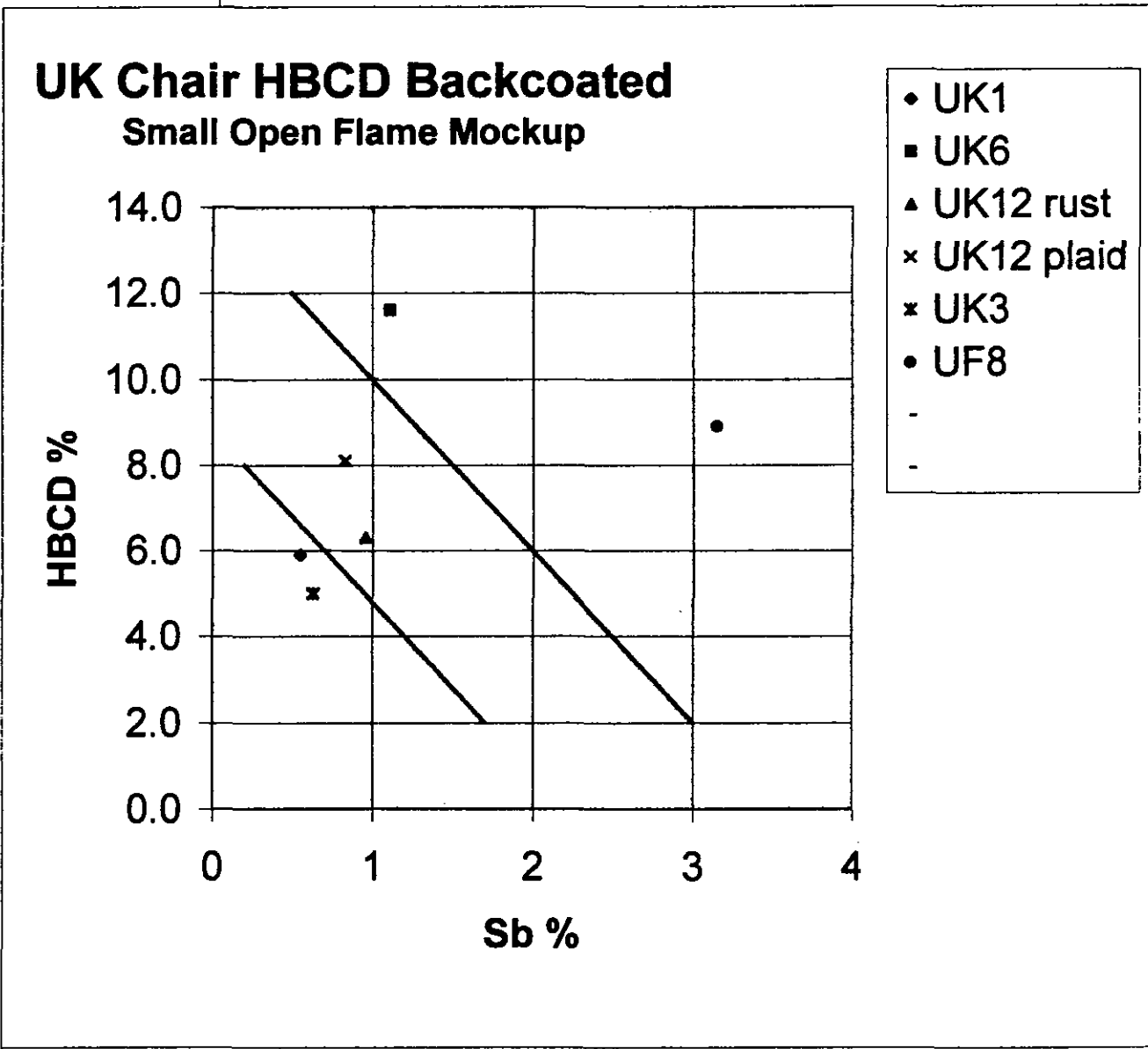
Note: Green = passed full scale small open flame test, Red = failed small open flame test,
 Green Line: Fabrics with FR chemical levels above this line generally pass flammability test
 Orange Line: Fabrics with FR chemical levels below this line generally fail flammability test
 Fabrics with FR chemical levels between the Green and Orange lines have mixed results

failed 4 of 6

Figure 2.

Sample #	Sb %	HBCD %	Number of Tests
UK1	0.55	5.9	Average of 6
UK3	0.63	5.0	Average of 2
UK6	1.11	11.6	Average of 15
UK12 rust	0.96	6.3	Average of 4
UK12 plaid	0.83	8.1	Average of 16
UF8	3.15	8.9	Average of 2

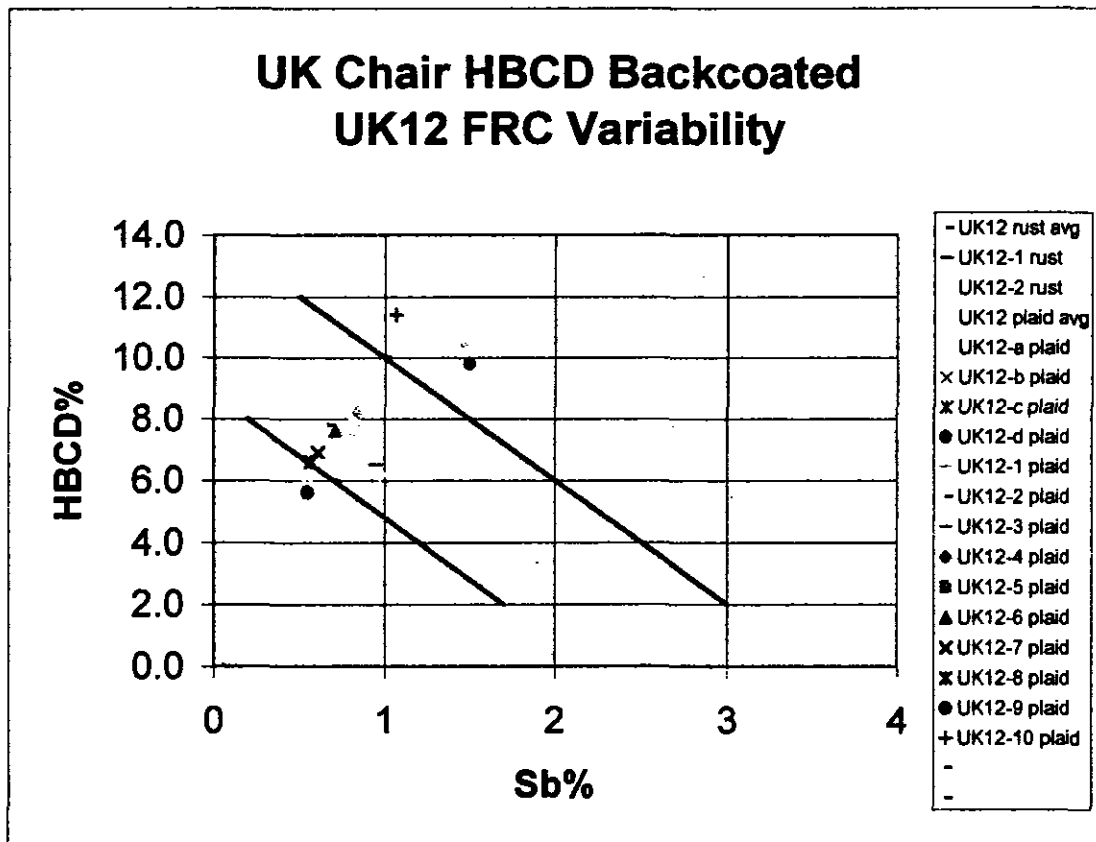
The relationship of Sb and HBCD to small open flame mockup tests are depicted below.
This graph shows that as FRC levels increased the tendency for passing small open testing increased



Note: Green = pass small open flame mockup test
Green Line: Fabrics with FR chemical levels above this line generally pass flammability test
Orange Line: Fabrics with FR chemical levels below this line generally fail flammability test
Fabrics with FR chemical levels between the Green and Orange lines have mixed results

Figure 3.

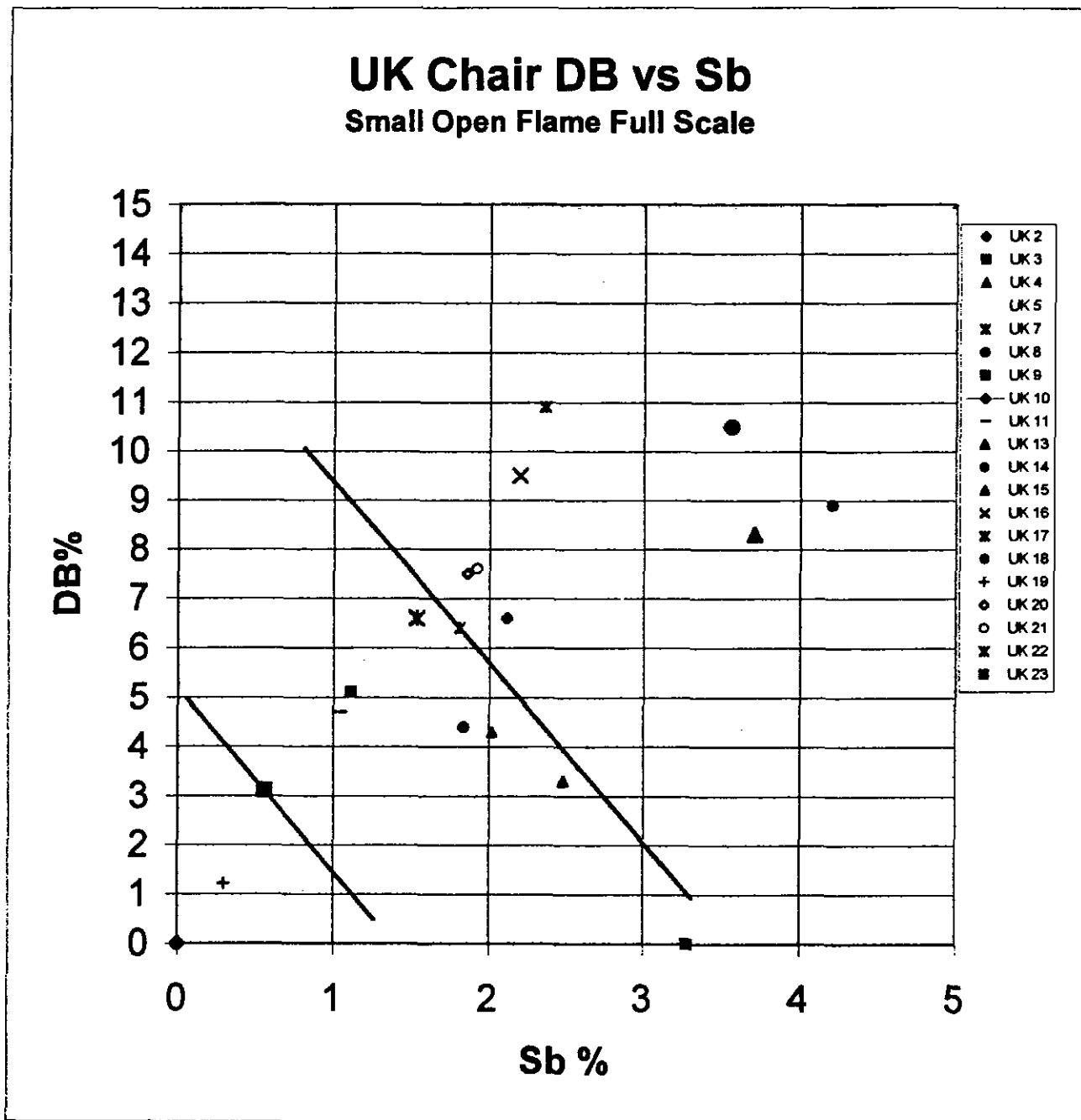
Sample #	Sb	HBCD
UK12 rust avg	0.96	6.3
UK12-1 rust	0.95	6.5
UK12-2 rust	0.97	6.2
UK12 plaid avg	0.83	8.1
UK12-a plaid	0.75	10.7
UK12-b plaid	0.55	6.1
UK12-c plaid	1.47	10.3
UK12-d plaid	1.5	9.8
UK12-1 plaid	0.61	6.4
UK12-2 plaid	0.67	7.8
UK12-3 plaid	0.68	7.6
UK12-4 plaid	0.85	8.2
UK12-5 plaid	0.82	7.6
UK12-6 plaid	0.71	7.6
UK12-7 plaid	0.61	6.9
UK12-8 plaid	0.57	6.6
UK12-9 plaid	0.55	5.6
UK12-10 plaid	1.07	11.4



Green Line: Fabrics with FR chemical levels above this line generally pass flammability test
Orange Line: Fabrics with FR chemical levels below this line generally fail flammability test
Fabrics with FR chemical levels between the Green and Orange lines have mixed results
The above graph shows the FRC variability found for UK12. This specimen had FRC levels in all 3 of the zones noted in the graph

Figure 4.

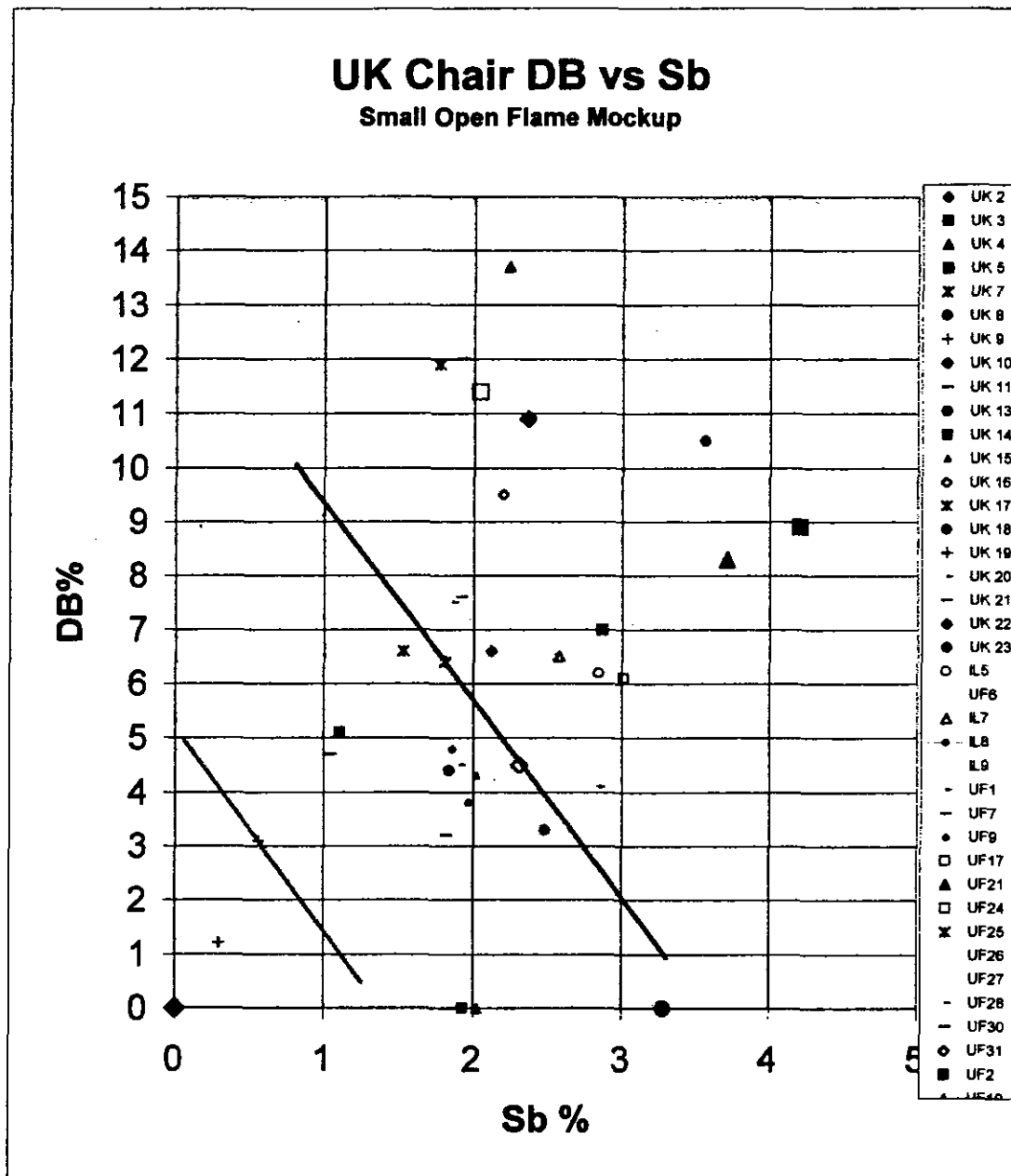
The graph below depicts the relationship of Sb and DB to full-scale small open flame testing
 This graph shows that as FRC levels increased the tendency for passing small open testing increased



Note: Green = passed full scale small open flame, Red = failed small open flame
 failed small open flame test with following explanations:
 UK5 failed 1 of 6 tests by flame at a loose fitting sight with big air gap
 Green Line: Fabrics with FR chemical levels above this line generally pass flammability test
 Orange Line: Fabrics with FR chemical levels below this line generally fail flammability test
 Fabrics with FR chemical levels between the Green and Orange lines have mixed results

Figure 5.

The graph below depicts the relationship of Sb and DB to mockup small open flame testing
This graph shows that as FRC levels increased the tendency for passing small open testing increased



Note: Green = pass small open flame mockup test, Red = failed small open flame mockup test

Yellow failed small open flame mockup test with following explanations:

IL9 was a thick weave fabric that only failed by glow/smoke

UF27 Self extinguished, but flame reached top of mockup before 2 minutes on 1 of 2 tests

UF26 is a cotton fabric that failed 2 of 2 tests by flame

UF6 is a cotton fabric that failed 1 of 3 tests

Green Line: Fabrics with FR chemical levels above this line generally pass flammability test

Orange Line: Fabrics with FR chemical levels below this line generally fail flammability test

Fabrics with FR chemical levels between the Green and Orange lines have mixed results

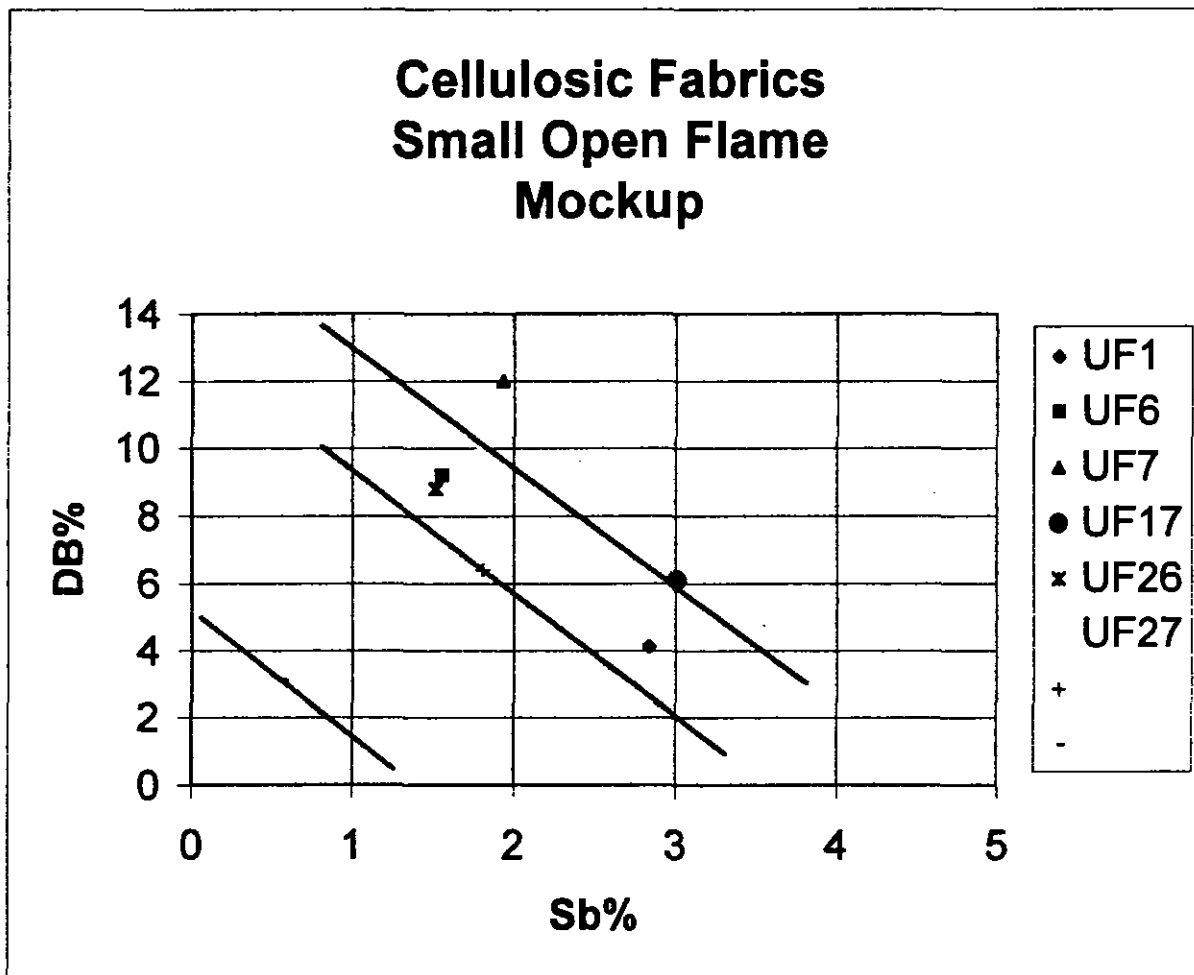
Figure 6.

Cotton Fabrics

FRC vs Flammability

Sample #	Sb	DB	HBCD	Wt(oz/yd ²)	Open Flame Mockup
UF1	2.84	4.1		13	pass
UF6	1.56	9.2		16.2	pass
UF7	1.93	12		12.7	pass
UF17	3.01	6.1		8.3	pass
UF26	1.52	8.8		11	fail
UF27	1.81	10.1		11	fail

The graph below depicts the relationship of Sb and DB to small open flame tests for cellulosic fabrics
Cellulosic fabrics appear to require more FRC to pass small open flame testing



Note: Green= passed small open flame test, Red = failed small open flame test,
= failed with following explanation:

UF27 failed 1 of 2 tests, self extinguished but flame reached top of mockup before 120 seconds

Green Line: Fabrics with FR chemical levels above this line generally pass flammability test

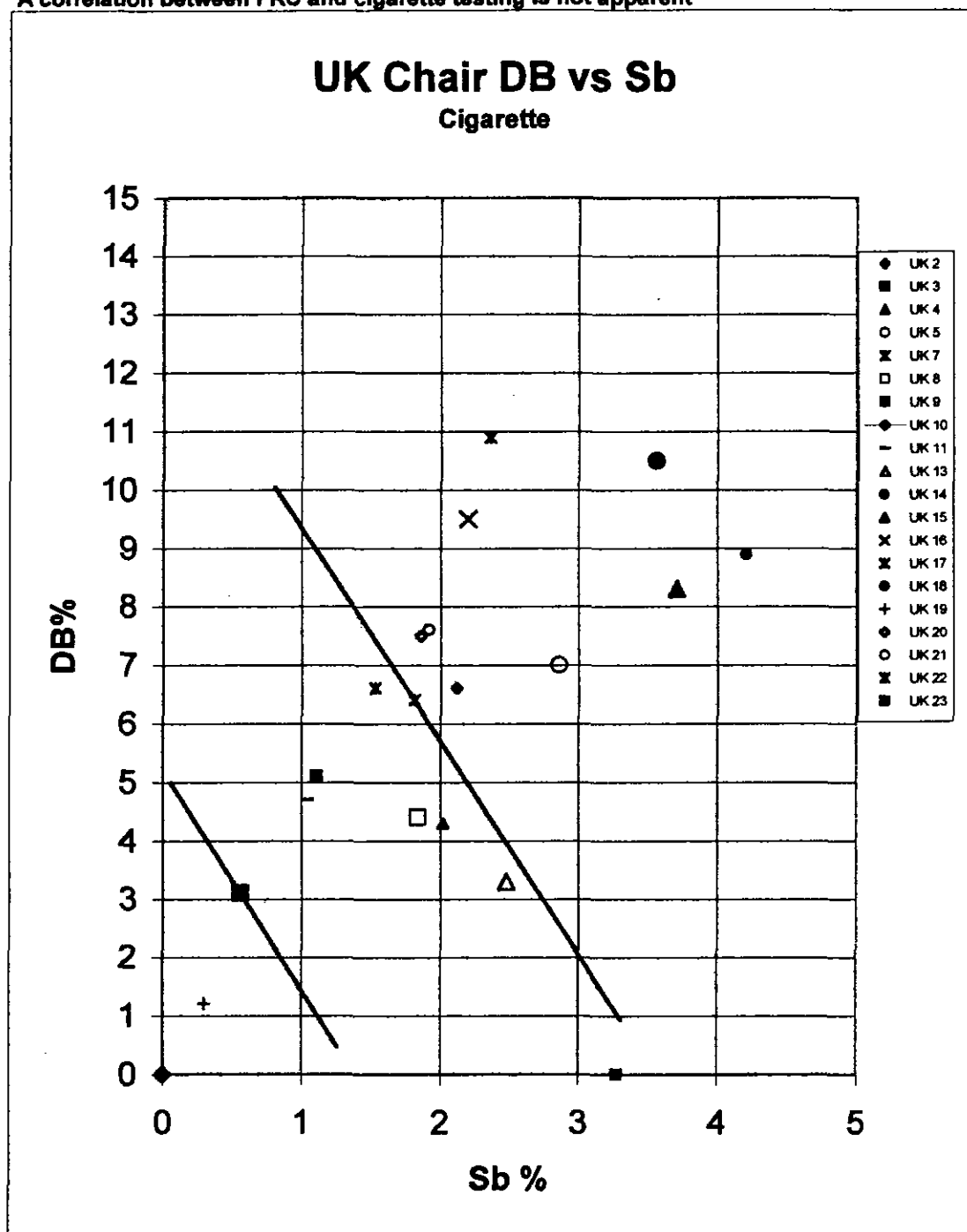
Orange Line: Fabrics with FR chemical levels below this line generally fail flammability test

Fabrics with FR chemical levels between the Green and Orange lines have mixed results

100% Cotton fabrics may require higher FR chemical loads as is represented in the Blue Line

Figure 7.

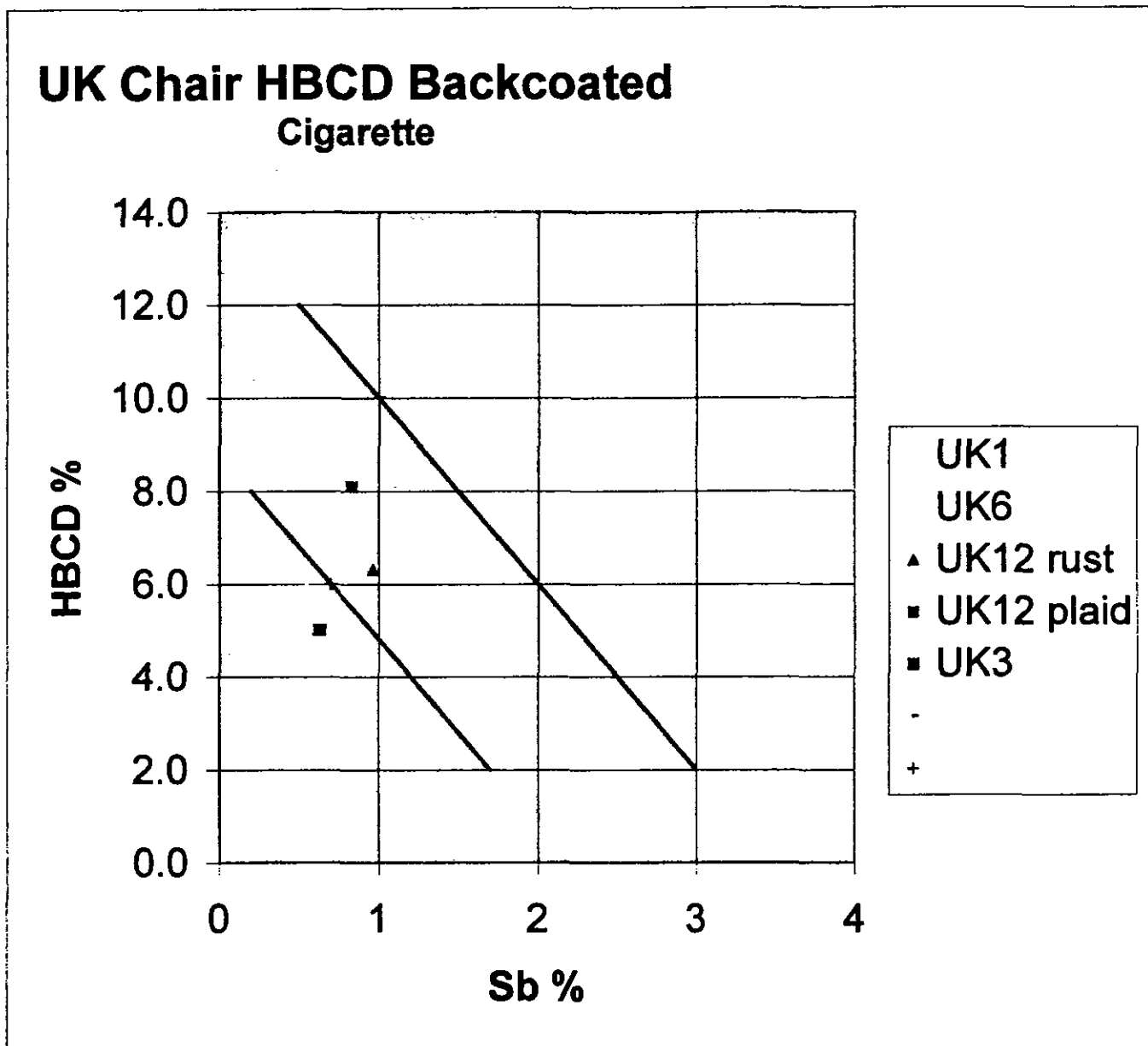
The graph below depicts the relationship of Sb and DB toward cigarette testing
A correlation between FRC and cigarette testing is not apparent



Note: All DB backcoated fabrics passed cigarette testing with the exception of UK3.
This chair consisted of 2 fabrics, one of which was cotton with HBCD backcoating
Green Line: Fabrics with FR chemical levels above this line generally pass flammability test
Orange Line: Fabrics with FR chemical levels below this line generally fail flammability test
Fabrics with FR chemical levels between the Green and Orange lines have mixed results

Figure 8.

The graph below depicts the relationship of Sb and HBCD toward cigarette testing
A correlation between FRC and cigarette testing is not apparent



Note: Red failed both mockup and full scale, passed full scale but failed mockup,
Orange failed full scale not tested mockup
Green Line: Fabrics with FR chemical levels above this line generally pass flammability test
Orange Line: Fabrics with FR chemical levels below this line generally fail flammability test
Fabrics with FR chemical levels between the Green and Orange lines have mixed results

Figure 9.



UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

Date: May 30, 2000

TO : Dale Ray, Directorate for Economic Analysis, Project Manager
Upholstered Furniture

THROUGH: Andrew G. Stadnik, Associate Executive Director, Directorate for
Laboratory Sciences

Robert T. Garrett, Director, Division of Electrical Engineering *RTG*

FROM : Gail Stafford, Division of Electrical Engineering *GS*
Andrew Bernatz, Division of Electrical Engineering *AB*

SUBJECT : UFAC vs. CPSC Cigarette Tests of Upholstery Fabrics

SUMMARY

The Directorate for Laboratory Sciences (LS) evaluated 40 upholstery fabrics for cigarette ignition resistance using two different test methods. Fabrics with and without flame retardant (FR) backcoatings and fireblocker backings were included in the study. The majority of the 40 fabrics tested resisted ignition from a smoldering cigarette.

BACKGROUND

These tests were conducted to expand the data base on cigarette ignition resistance of fabrics for which LS also has small open flame test data. To evaluate the cigarette ignition resistance of the fabrics, LS staff used the test protocol in the Upholstered Furniture Action Council (UFAC) Fabric Classification Test Method¹ and a modified version of the UFAC procedure using the seating area mock-up specified in the Draft CPSC Small Open Flame Standard².

Fabrics were received from five textile manufacturers and one fabric converter. A fabric identification code was assigned to each fabric, and these codes were used throughout the Upholstered Furniture Project to uniformly identify the fabrics. A total of 40 fabrics were included in the study.

¹ Superscript refers to reference numbers on page 9.

- Chemical analysis of seven fabrics by LS staff verified that four of them contained a FR backcoating, while three fabrics were not FR-treated.^{3,4,5} Tables 1 and 2 provide the fabric identifications for these non-FR and FR backcoated fabrics respectively.
- One manufacturer provided 11 non-FR backcoated fabrics and 12 of the same fabrics that were FR backcoated. Information from the manufacturer indicated that two different types of FR backcoatings were used. Fabric identifications for these sets of fabrics (with and without an FR backcoating) are given in Tables 3 and 4.
- Another manufacturer provided five fabrics with an aramid fireblocker backing as well as the same fabrics without the fireblocker. Table 5 provides the fabric identifications for these sets of fabrics (with and without the fireblocker).

TEST PROGRAM

Two protocols were used to evaluate the cigarette (smoldering) ignition resistance of the fabrics. In the first protocol, the UFAC Fabric Classification Test Method was used. The test fabric was placed over the standard UFAC polyurethane foam using a small wooden seat mock-up placed inside an enclosure. The lit cigarette was placed in the crevice and covered with a piece of unlaundered sheeting fabric. A test consists of three mock-ups with one cigarette test location per mock-up. Fabrics with a vertical char of less than 1.75 inches above the mock-up crevice are considered UFAC Class I fabrics. All other fabrics are Class II (and require an approved barrier between the cover fabric and polyurethane foam in the horizontal seating area).

The conditioning requirements specified in the UFAC test protocol were followed. Test fabric specimens and standard foam were conditioned for at least 4 continuous hours prior to testing at a temperature of $21 \pm 3^{\circ}\text{C}$ and 50 to 60% relative humidity.

In the second protocol, called the CPSC cigarette test protocol, a modified version of the UFAC protocol was used. The fabrics were placed over the standard polyurethane foam specified in the CPSC draft protocol using the seating area test mock-up, but without a UFAC-type enclosure. A test consists of one mock-up with three cigarette test locations per mock-up. Each lit cigarette was placed in the crevice and covered with a piece of unlaundered sheeting fabric. Char lengths were measured from the crevice on both the vertical and horizontal panels.

For the CPSC cigarette test protocol, one fabric was tested with the mock-up seat/back angle set at 95° instead of the 90° angle specified in the draft standard; and two fabrics were tested with the seat/back angle at both 90° and 95° . The variation was made to see if the geometry of the seat/back angle affected the cigarette ignition resistance of these fabrics. In order to set the mock-up seat/back angle at 95° , the following modifications were made.

- The bolts that hold the mock-up seat and back frames together were removed.
- The seat and back frames were secured together using two small C-clamps (instead of the bolts.)
- The C-clamps were loosened just enough to allow the back frame to move.
- The angle was set using an angle finder.
- The C-clamps were re-tightened.
- The angle was checked again.

As specified in the CPSC draft upholstered furniture flammability standard, the conditioning period for the test fabrics and standard foam was 24 continuous hours prior to testing. The fabrics and foam were conditioned at $21 \pm 3^\circ \text{C}$ and 50 to 60% relative humidity using the conditioning requirements of the UFAC test protocol. These atmospheric conditions are different than the temperature ($25 \pm 2^\circ \text{C}$) and relative humidity (40 to 50%) specified in the CPSC draft standard.

RESULTS

Table 1 summarizes the flammability test results for three non-FR fabrics. Fabrics UF 19 and UF 22 showed good resistance to cigarette ignition. Both fabrics (a cotton and a blend) were UFAC Class I and performed well when tested using the CPSC seat mock-up protocol (at 90°), with all char lengths less than 1.0 inch. Fabric UF 19 also performed well by resisting ignition from a cigarette with the CPSC mock-up seat/back angle set at 95° . The non-FR cotton fabric UF 54 was UFAC Class II with obvious ignitions, and it also ignited using the CPSC seat mock-up protocol.

Table 1.
NON-FR FABRICS
UFAC vs. CPSC CIGARETTE TESTS

FABRIC IDENTIFICATION	CIGARETTE TESTS Char lengths 0.1 inch		
	UFAC FABRIC CLASS	CPSC	
	Vertical	Vertical	Horizontal
UF 19 Non-FR, Cotton, 12.0 oz/yd ²	≤ 0.8 Class I	≤ 0.6 $\leq 0.3^*$	0.5 0.2*
UF 54 Non-FR, Cotton, 4.4 oz/yd ²	$\leq 5.0^{**}$ Class II $\leq 0.7^{**}$ Class II horizontal char = 5.0	$\leq 0.9^{**}$ $\leq 2.2^{**}$ $\leq 6.0^{**}$	$\leq 3.3^{**}$ $\leq 3.4^{**}$ 3.5**
UF 22 Non-FR, Blend, 10.3 oz/yd ²	≤ 0.5 Class I	0.5	0.5

* Tested with seat/back angle at 95° .

** At least one cigarette test location ignited.

As shown in Table 2, all four FR backcoated fabrics exhibited good cigarette ignition resistance. All were UFAC Class I, and fabrics UF 21, UF 4 and UF 18 performed well using the CPSC seat mock-up protocol with all char lengths less than 1.0 inch. Fabrics UF 5 and UF 18 were tested for cigarette ignition resistance with the CPSC seat/back mock-up angle at 95°, and both fabrics had vertical and horizontal char lengths less than 1.0 inch. Fabrics UF 5 and UF 21 were a thermoplastic, while UF 4 and UF 18 were blends.

Table 2.
FR BACKCOATED FABRICS
UFAC vs. CPSC CIGARETTE TESTS

FABRIC IDENTIFICATION	CIGARETTE TESTS Char lengths 0.1 inch		
	UFAC FABRIC CLASS	CPSC	
	Vertical	Vertical	Horizontal
UF 5 FR Backcoated, Olefin, 8.8 oz/yd ²	≤0.9 Class I	≤0.6*	≤0.4*
UF 21 FR Backcoated, Olefin, 9.5 oz/yd ²	≤0.9 Class I	0.7	≤0.6
UF 4 FR Backcoated, Blend, 11.0 oz/yd ²	0.5 Class I	≤0.6	0.5
UF 18 FR Backcoated, Blend, 11.9 oz/yd ²	SE Class I	≤0.5 ≤0.6*	≤0.6 ≤0.6*

*Tested with seat/back angle at 95°.

SE means cigarettes self-extinguished before burning their entire length.

Table 3 summarizes the flammability test results for the sets of uncoated and FR backcoated cotton fabrics. Cotton fabrics UF 1a and UF 1 were not tested using the CPSC procedure, but both the non-FR and FR backcoated fabrics were UFAC Class I. As might be expected, the non-FR cotton fabric UF 6a ignited; while its corresponding FR backcoated fabric (UF 6) resisted ignition with the CPSC test. However, some unexpected results were observed with three sets of cotton fabrics .

- Cotton fabrics UF 7a and UF 7 were not tested using the UFAC procedure, but both the non-FR and its corresponding FR backcoated fabric ignited during the CPSC seat mock-up test.
- During the CPSC test the non-FR cotton fabric UF 26a resisted ignition; while fabric UF 26 with the FR backcoating ignited both the vertical and horizontal panels of the CPSC seat mock-up. However, both the non-FR and FR backcoated fabrics were UFAC Class I.
- Fabrics UF 27a and UF 27 were not tested using the UFAC procedure, but were tested with the CPSC seat mock-up. The non-FR cotton fabric (UF 27a) resisted ignition, but its corresponding FR backcoated fabric (UF 27) ignited both the vertical and horizontal panels of the CPSC mock-up.

**Table 3. COTTON FABRICS
WITH & WITHOUT FR BACKCOATING
UFAC vs. CPSC CIGARETTE TESTS**

FABRIC IDENTIFICATION	CIGARETTE TESTS Char lengths 0.1 inch		
	UFAC FABRIC CLASS	CPSC	
	Vertical	Vertical	Horizontal
UF 1a Non-FR, Cotton, 10.0 oz/yd ²	0.7† Class I	NT	NT
UF 1 □ FR Backcoated, Cotton 13.0 oz/yd ²	0.9† Class I	NT	NT
UF 6a Non-FR, Cotton, 12.5 oz/yd ²	NT	≤3.1*	≤2.9*
UF 6 ● FR Backcoated, Cotton, 16.2 oz/yd ²	NT	SE	SE
UF 7a Non-FR, Cotton, 8.2 oz/yd ²	NT	≤2.2*	≤2.9*
UF 7 ● FR Backcoated, Cotton, 12.7 oz/yd ²	NT	≤2.5*	≤2.7*
UF 26a Non-FR, Cotton, 9.0 oz/yd ²	≤0.6† Class I	0.5	0.5
UF 26 ● FR Backcoated, Cotton, 11.0 oz/yd ²	≤0.6 Class I	≤2.2*	≤2.6*
UF 27a Non-FR, Cotton, 8.5 oz/yd ²	NT	≤0.5	≤0.5
UF 27 ● FR Backcoated, Cotton, 11.0 oz/yd ²	NT	≤3.8*	≤2.9*

† Two mock-ups tested.

NT means not tested because there was not enough fabric.

* At least one cigarette test location ignited.

SE means cigarettes self-extinguished before burning their entire length.

□ Same type of FR backcoating.

● Same type of FR backcoating.

All six sets of blend fabrics , as shown in Table 4, with and without a FR backcoating resisted ignition during the UFAC and/or CPSC tests.

Table 4. **BLEND FABRICS
WITH & WITHOUT FR BACKCOATING
UFAC vs. CPSC CIGARETTE TESTS**

FABRIC IDENTIFICATION	CIGARETTE TESTS Char lengths 0.1 inch		
	UFAC FABRIC CLASS	CPSC	
	Vertical	Vertical	Horizontal
UF 4a Non-FR, Blend, 9.0 oz/yd ²	≤0.7 Class I	≤0.5	≤0.5
UF 4 ● FR Backcoated, Blend, 12.5 oz/yd ²	SE Class I	SE	SE
UF 8a Non-FR, Blend, 9.5 oz/yd ²	NT	0.5	0.4
UF 8 □ FR Backcoated, Blend, 14.0 oz/yd ²	SE Class I	SE	SE
UF 9 □ Lightly FR Backcoated, Blend, 12.5 oz/yd ²	≤0.7 Class I	0.5	≤0.5
UF 10a Non-FR, Blend, 9.7 oz/yd ²	NT	≤0.5	0.4
UF 10 ● FR Backcoated, Blend, 13.2 oz/yd ²	NT	SE	SE
UF 24a Non-FR, Blend, 8.5 oz/yd ²	≤0.5 Class I	NT	NT
UF 24 ● FR Backcoated, Blend, 11.7 oz/yd ²	≤0.7 Class I	SE	SE
UF 25a Non-FR, Blend, 6.5 oz/yd ²	NT	≤0.7	0.5
UF 25 ● FR Backcoated, Blend, 9.2 oz/yd ²	NT	SE	SE
UF 28a Non-FR, Blend, 9.7 oz/yd ²	NT	0.6	0.5
UF 28 □ FR Backcoated, Blend, 13.0 oz/yd ²	≤0.7 Class I	≤0.8	≤0.6

SE means cigarettes self-extinguished before burning their entire length.
NT means not tested because there was not enough fabric.

□ Same type of FR backcoating.
● Same type of FR backcoating.

The cigarette test results for the fabrics with and without the aramid fireblocker are summarized in Table 5. All five pairs of fabrics with and without the fireblocker backing performed well. Each fabric was UFAC Class I, and had vertical and horizontal char lengths less than 1.0 inch with the CPSC seat mock-up protocol. Fabrics UF 43/44, UF 45/46, UF 48/49, and UF 50/51 are thermoplastics, while UF 52/53 are cotton.

Table 5.
FABRICS WITH & WITHOUT FIREBLOCKER
UFAC vs. CPSC CIGARETTE TESTS

FABRIC IDENTIFICATION	CIGARETTE TESTS char lengths 0.1 inch		
	UFAC FABRIC CLASS	CPSC	
	Vertical	Vertical	Horizontal
UF 43 Non-FR, Nylon, 7.2 oz/yd ²	≤0.6 Class I	≤0.6	0.5
UF 44 FR Fireblocker, Nylon, 11.5 oz/yd ²	≤0.0 Class I	0.4	0.5
UF 45 Non-FR, Nylon, 6.9 oz/yd ²	≤0.5 Class I	0.5	≤0.5
UF 46 FR Fireblocker, Nylon, 11.3 oz/yd ²	≤0.4 Class I	0.3	0.4
UF 48 Non-FR, Polyester, 7.4 oz/yd ²	≤0.7 Class I	≤0.6	0.5
UF 49 FR Fireblocker, Polyester, 12.1 oz/yd ²	≤0.5 Class I	0.3	0.4
UF 50 Non-FR, Olefin, 5.8 oz/yd ²	≤1.1 Class I	0.6	0.6
UF 51 FR Fireblocker, Olefin, 10.1 oz/yd ²	≤0.8 Class I	≤0.7	0.5
UF 52 Non-FR, Cotton, 5.1 oz/yd ²	≤1.0 Class I	0.6	0.5
UF 53 FR Fireblocker, Cotton, 9.6 oz/yd ²	≤0.6 Class I	0.5	0.5

CONCLUSIONS

Twenty five of the 40 upholstery fabrics included in this study were tested for flammability using both the UFAC and CPSC cigarette ignition tests. The majority of these fabrics performed similarly using both test methods. With the UFAC Fabric Classification Test protocol 24 fabrics were Class I, and one fabric was Class II. The Class II non-FR cotton fabric (UF 54) ignited using both the UFAC and CPSC protocols. All but one of the 24 UFAC Class I fabrics exhibited good cigarette ignition resistance with the CPSC seat mock-up protocol. The Class I FR backcoated cotton fabric (UF 26) ignited during the CPSC seat mock-up test.

The majority of the 40 fabrics tested resisted ignition from a smoldering cigarette. Six fabrics did ignite from a cigarette using either the UFAC and/or CPSC procedures. All six fabrics (UF 54, UF 6a, UF 7a, UF 7, UF 26 and UF 27) that ignited are cotton, and three (UF 7, UF 26 and UF 27) of them are FR backcoated. Because cellulosic (i.e., cotton) fabrics are more likely to ignite from a cigarette than thermoplastic or blend fabrics, the ignition of the non-FR cotton fabrics could be expected. However, ignition of the FR backcoated fabrics (particularly the two whose corresponding non-FR fabrics resisted ignition) was unexpected. Information accompanying the fabrics indicated that the same type of FR backcoating was applied to the three backcoated fabrics that ignited. Perhaps that type of FR backcoating (i.e., antimony) was not appropriate for those fabrics to resist ignition from a cigarette, or the amount of the FR backcoating applied was not adequate.

No effect of seat/back geometry was observed with the three UFAC Class I fabrics (UF 19, UF 5 and UF 18) tested with the CPSC seat/back mock-up angle at 95°. All three fabrics resisted ignition. Fabrics UF 19 and UF 18 were also tested with the CPSC seat/back angle at 90°, and both resisted ignition.

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4. Memorandum To Dale Ray From Linda Fansler, LS, Chemical Identification Of Flame Retardant Polyurethane Foam and Upholstery Fabrics Backcoated With Flame Retardants, April 30, 1997, Consumer Product Safety Commission.
5. Data sheets summarizing chemical analysis of FR backcoated and non-FR backcoated upholstery fabrics performed by LS Division of Chemistry, April 16, 1998.



UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

Date: May 18, 2001

TO : Dale Ray, Upholstered Furniture Project Manager
Directorate for Economics

THROUGH: Sue Ahmed, Ph.D., Associate Executive Director *sa*
Directorate for Epidemiology

Russ Roegner, Ph.D., Director *RR*
Division of Hazard Analysis

FROM : Mark S. Levenson, Ph.D. *ML*
Division of Hazard Analysis

SUBJECT : Review of the cigarette ignition propensity of upholstered furniture meeting the draft small open-flame standard

1. Introduction

The Consumer Product Safety Commission (CPSC) is presently considering a mandatory standard to reduce the hazard associated with small open-flame ignitions of upholstered furniture. As part of its regulatory analysis, CPSC is evaluating cost and benefits of the standard¹. A significant component of the cost-benefit analysis is the effect the standard would have on fire losses from cigarette ignition of upholstered furniture. This memo addresses the evidence concerning this effect and in particular the statistical significance of the estimated effect. To address this issue the memo discusses:

- The relevant laboratory data
- Measures of cigarette ignition propensity as it relates to the cost-benefit analysis
- General issues related to statistical significance
- Results of statistical analysis of the laboratory data.

2. Data Sources

The data used in the cost-benefit analysis come from three separate laboratory studies conducted at CPSC on upholstered chairs. Table 1 summarizes the three laboratory studies and the data used in the cost-benefit analysis. The three studies generally attempted to choose chairs representative of market distributions. However, there were

¹ See C.L. Smith, Preliminary Analysis for a Mandatory Standard Addressing Small Open-Flame Ignitions of Upholstered Furniture (DRAFT), April 2001.

specific objectives and constraints of the studies, such as looking at UFAC compliance and effectiveness, which are not directly relevant to the present questions. Because of known differences in fire behavior of thermoplastic and cellulosic upholstery fabrics, the cost-benefit analysis treated these two classes of fabrics separately and combined the results based on the market share of the two fabrics.

Table 1: Summary of Laboratory Studies.

Study	Chairs Used in Study	Chairs Used in Cost-Benefit Analysis
1984 ²	40 UFAC Phase 2 chairs	24 untreated thermoplastic chairs
1996 ³	40 UFAC and 18 Non-UFAC chairs	34 untreated cellulosic and 22 untreated thermoplastics chairs
2000 ⁴	27 chairs from UK labs, manufacturers, and retailers	12 treated cellulosic and 8 treated thermoplastic chairs that passed the draft small open-flame standard

Two of the studies (the 1984 and 1996 studies) used chairs designed for use in the U.S. market, which do not have to conform to any standard for small open-flame ignition resistance. The third study (the 2000 study) used chairs manufactured in the United Kingdom that are designed to meet British standards for open-flame and cigarette ignition resistance. These chairs had various flame-retardant treatments to the upholstery fabrics. Chairs were selected from the British chairs that passed the CPSC draft small open-flame test. Table A1 of the appendix summarizes the relevant data from the studies as it relates to the current analysis.

Results from the first two studies are used in the cost-benefit analysis to represent current chairs with regard to cigarette ignition propensity in the U.S. These results are compared to those of the selected chairs from the third study, which are used to represent chairs after the adoption of the CPSC draft small open-flame standard. The validity of conclusions on changes in cigarette ignition propensity from the adoption of the CPSC small open-flame standard depends on the extent that the two classes of chairs represent the market conditions with and without the standard.

It seems reasonable that the first two studies provide results that are representative of the present market conditions. However, what might be questioned is the extent that the British chairs, which are flame retardant treated and passed the small open-flame test, represent the market conditions with the adoption of the standard. For example, it might be possible to pass the small open-flame test without flame retardant treatment and still have a significant cigarette ignition propensity. If such a chair is possible, it is not

² See P. Fairall, Analysis of CPSC 40 Chair Test Program (UFAC Phase 2 Furniture), May 1984.

³ See G. Stafford and L. Fansler, Upholstered Furniture Flammability Testing: Cigarette Ignition Data Analysis, July 1996.

⁴ See L. Fansler, UK Chair and Mockup Test Results, October 2000.

represented in the analysis. In addition, the British standards address cigarette ignition. Chairs meeting the CPSC draft standard would not be required to meet any cigarette ignition standard.

However, it is noteworthy that only 20 of the 27 UK chairs passed the small open-flame test. From this fact, it is arguable that the 27 chairs span a range of ignition resistance. Thus, the 20 chairs that passed the small open-flame test might represent a range of chairs that would meet the standard. Such a set of chairs is what is required for the validity of conclusions on the effect of the small open-flame standard based on these data.

3. Measures of Ignition Propensity

To properly address the effect of the small open-flame standard on cigarette ignition propensity for the cost-benefit analysis, the specific measure of cigarette ignition propensity must be considered. Assume that the present fire losses associated with cigarette ignitions of upholstered furniture is C . The value of C comes from national databases and surveys.⁵ There is a certain probability of a piece of furniture being involved in a cigarette-ignited fire without a small open-flame standard. Call this value p . Likewise, there is a probability of such an event with a small open-flame standard. Call

this value q . The fire losses with the adoption of the small open-flame standard is $\frac{q}{p}C$

and the reduction in losses from the standard is $\left(1 - \frac{q}{p}\right)C$. The key quantity we are

interested in is $r = \left(1 - \frac{q}{p}\right)$.

Each of the two probabilities in r depends on the probability that a cigarette will encounter the furniture and the probability that it will ignite given it has encountered the furniture. Since the probability of a cigarette encountering the furniture does not depend on the draft standard, only the ratio of the probability of ignition without and with the standard is necessary. For the remainder of the memo, p and q will represent these probabilities, respectively

The data sources described in the previous section are used to estimate p and q . Depending on the study and particular chair, 3 to 5 locations on a chair were tested. The locations were predetermined and included areas such as the seat, back, side, and welt. Each location was generally tested 3 times for cigarette ignition, resulting in around 9 to 15 tests per chair. The probabilities of interest, p and q , were each estimated in two ways.

Consider a single chair. The first estimate, referred to as the discrete estimate, is equal to the value of one if any of the multiple tests for the chair resulted in ignition and equal to the value of zero if there were no ignitions. The second estimate of the probability, referred to as the continuous estimate, uses the fraction of ignitions for the chair. For

⁵ See K. Ault and M. Levenson, Upholstered Furniture Fires Loss Estimates 1980 –1998, February 2001.

example, if a chair was tested 12 times and there were 4 ignitions, then the discrete estimate would be one and the continuous estimate would be 1/3. An overall estimate of the probability for a class of chairs is formed by averaging the values of the individual chair estimates in the class.

The continuous measure may better represent the probability because it gives the frequency of ignitions of multiple tests and is not affected by the number of tests performed. Ideally, one would weight the results of the tests of the various chair locations to reflect the areas of the chair more likely to encounter a cigarette. Since it is unlikely any reliable information is available for such weighting, an unweighted measure is a good compromise.

Because it is known that cellulosic and thermoplastics fabrics behave differently, separate estimates of both p and q were calculated for each of the two classes of fabrics and combined weighted by their respective market shares to give the expected probabilities for the market. Table 2 defines notation for the market weights and the ignition probabilities of the two classes of fabrics.

Table 2: Notation for Fabric Weights and Ignition Probabilities.

	Market Share Weights	With SOF Standard	Without SOF Standard
Cellulosic	w_c	q_c	p_c
Thermoplastic	w_t	q_t	p_t

The estimates of p and q are $p = w_c p_c + w_t p_t$ and $q = w_c q_c + w_t q_t$, respectively. The market weights are assumed to be known accurately and are scaled to sum to one.

4. Statistical Significance

Statistical significance testing is a common and accepted procedure to demonstrate rigorously that an effect is real and not just an artifact of random variation. In the present case, we are interested in the effect of the small open-flame standard on cigarette ignitions. Statistical significance testing starts by defining a *null hypothesis* about the effect. The null hypothesis is a statement about the effect that you wish to demonstrate is false. For example in the present case, the null hypothesis might be that there is no effect on cigarette ignitions.

Based on statistical considerations, a data dependent decision rule is created. The rule has the property that there is a certain accepted probability that the null hypothesis is declared false, given that it is actually true. This probability, called the significance level, is stated in the design of the experiment stage. Different fields and applications have accepted values for the significance level, but the typical values are 0.01, 0.05, and 0.1. The smallest level in which the null hypothesis is rejected is called the p-value. Thus, a p-

value of 0.04 implies that the null hypothesis can be rejected at the 0.05 level. Note that failure to reject the null hypothesis does not imply that it is true.

The specific statement of the null hypothesis affects the p-value. For example, consider the following two forms of the null hypothesis for the present problem.

Null Hypothesis I: The small open-flame standard results in no change or an increase in cigarette ignitions.

Null Hypothesis II: The small open-flame standard results in no change in cigarette ignitions.

Rejecting either of these statements supports the adoption of the small open-flame standard. The first statement is known as a one-tailed test, because only evidence that there is a decrease in ignitions is taken as evidence against the null hypothesis. The second statement is known as a two-tailed test, because evidence of a decrease or an increase in cigarette ignitions is taken as evidence against the null hypothesis.

There is an important practical difference between the two hypotheses. For the two-tailed test, a larger decrease in cigarette ignitions is needed to reject the null hypothesis than in the one-tail test.⁶ Another way of saying this is that a p-value for the one-tailed test is typically one half the size of the comparable p-value for the two-test. Recall smaller p-values provide greater evidence that the null hypothesis is not true. Because the two-tailed test results in a less significant p-value, it is considered more conservative and often used by default.

The proper choice of the two null hypotheses depends on the decisions that will be made based on rejecting the null hypothesis. If an increase in cigarette ignitions results in the same decision as if there is no effect then the one-tail test is appropriate. A possible justification for this decision rule is that if we see no effect or an increase in ignitions, we will not go forward with the draft standard.

If an increase in cigarette ignitions results in a different decision than if there is no effect then the two-tail test is appropriate. A possible justification for this decision rule is that we have justified the small open-flame standard based on small open-flame considerations and need to evaluate the effect, positive or negative, of the standard on cigarette ignitions.

There is an opinion among statisticians that statistical significance testing is overused. In particular, statistical significance has no bearing on the size of an effect. A very small effect with no engineering or scientific significance can be statistically significant. Additionally, too much emphasis is often placed on certain values of the p-value such as 0.05. Results just slightly less significant than 0.05 may improperly be ignored.

⁶ The reason for this is that in the two-tailed test, the probability of falsely rejecting the null hypothesis is divided in two to account for both a decrease and an increase.

The use of standard errors and confidence intervals often provide an improved alternative to statistical significance testing. Standard errors give a measure of the variation of an estimated effect. For example, the estimated effect on the reduction in cigarette ignitions might be 60% with a standard error of 25%. The interval of values defined by the estimated effect plus and minus two standard errors often provides an approximate 95% *confidence interval*. Such an interval contains the true value 95% of the time. Unlike statistical significance testing, confidence intervals provide likely values of the effect and thus provide a measure of the size of the effect. Perhaps the common preference for statistical significance testing over confidence intervals is that the former provides a yes/no answer, whereas the latter require some interpretation.⁷

5. Results and Conclusions

Table 3 gives 95% confidence intervals and one- and two-tail p-values for the percent reduction in cigarette ignition, r (see Section 3). The information is given for r based on the discrete and continuous measure of the ignition probability. The appendix provides details on the derivation of these values.

Table 3: Summary of the statistical significance of the effect on cigarette ignition, r .

	Continuous Measure	Discrete Measure
95% Confidence Interval	$79 \pm 25\%$	$61 \pm 61\%$
P-Value of One Tail Test	0.000	0.025
P-Value of Two-Tail Test	0.000	0.049

Based on the continuous measure of ignition probability, the small open-flame standard reduces cigarette ignitions. The effect is highly statistically significant regardless of whether the statistical significance testing is performed with a one- or two-tailed test.

Based on the discrete measure of cigarette ignition probability, both the one- and two-tail tests are significant at the 0.05 level. However, the calculated p-value of the two-tail result is nearly 0.05. It is for this reason that the lower limit of the 95% confidence interval based on the discrete measure is effectively zero. Since certain approximations are used in these calculations, as described in the appendix, the actual significance of the result may be less than or greater than 0.05.

Section 2 discussed the appropriateness of the available data to address the effect of the small open-flame standard. An argument was made for the appropriateness of the data. Section 3 argued that the continuous measure is a good measure of ignition probability. Thus, it can be reasonably concluded that the small open-flame standard results in a statistically significant decrease in cigarette ignitions.

⁷ There is an equivalence between confidence intervals and statistical significance testing. If the value of zero falls outside the 95% confidence interval, then the null hypothesis that there is no effect is rejected at a level of 0.05.

Appendix

Table A1 provides summary information for all the data used in the present analysis. Refer to the introduction and Table 1 for the sources of the data.

Table A1: Laboratory results summary.

	Treated and Passed SOF Test	Untreated
Cellulosic ($w_c = .36$)	$n = 12$ $x = 3$ $p = 0.25$ $\bar{y} = 0.058$ $s(y) = 0.12$	$n = 34$ $x = 18$ $p = 0.53$ $\bar{y} = 0.257$ $s(y) = 0.35$
Thermoplastic ($w_t = .64$)	$n = 8$ $x = 0$ $p = 0$ $\bar{y} = 0$ $s(y) = 0$	$n = 46$ $x = 3$ $p = 0.065$ $\bar{y} = 0.014$ $s(y) = 0.060$

n = Number of chairs

x = Number of chairs with at least one ignition

$p = x / n$

\bar{y} = Mean of the fraction of ignitions⁸

$s(y)$ = Standard deviation of the fraction of ignitions

w = Market share weight of fabric

The statistical analysis given in section 5 is based on common practices of uncertainty analysis used in science and engineering.⁹ Such an analysis is based on variance calculations and normal approximations.

Recall $p = w_c p_c + w_t p_t$ and $q = w_c q_c + w_t q_t$. The values of p_c , p_t , q_c , and q_t may be based on the discrete or continuous measures of the ignition probabilities. Using the notation of Table A1, the variance of the discrete measure of one of these quantities is equal to $p(1 - p) / n$ and the variance of the continuous measure is $s(y) / \sqrt{n}$.¹⁰ The variance of p and q are respectively:

$$\text{var}(p) = w_c^2 \text{var}(p_c) + w_t^2 \text{var}(p_t) \text{ and}$$

⁸ To calculate \bar{y} and $s(y)$, the fraction of ignition for each chair in the category is calculated. \bar{y} and $s(y)$ are the mean and standard deviation of these values.

⁹ For a review of such practices see P. Bevington and D. Robinson, Data Reduction and Error Analysis for the Physical Sciences, 1991.

¹⁰ For the case, when $p=0$, $p=0.5/n$ is used in the variance calculation of the discrete measure.

$$\text{var}(q) = w_c^2 \text{var}(q_c) + w_t^2 \text{var}(q_t).$$

The variance of $r = \left(1 - \frac{q}{p}\right)$ is $\text{var}(r) \approx \left[\text{var}(q)/q^2 + \text{var}(p)/p^2\right](q/p)^2$.

The above analysis can be expected to provide a good estimate for the confidence intervals and p-values associated with the continuous measure. To check the analysis of the discrete measure, a bootstrap procedure was used. For each fabric a pooled estimate of the ignition propensity was calculated. The estimate was equal to the total number of chairs with an ignition divided by the total number of chairs for the fabric. For each fabric, using the pooled estimate of the ignition propensity, simulated data were generated for both the treated and untreated case based on the binomial distribution with the number of chairs equal to the actual number of chairs tested. The p-values are based on the fraction of the simulations that produced a value of r greater (for the one-tail p-value) or greater in absolute value (for the two-tail p-value) than the observed value of r . The one- and two-tailed p-values are 0.034 and 0.132, respectively. Note that the distribution of the value of r is not symmetrical and therefore, the two-tail p-value is not equal to twice the one-tail p-value.